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Lane, B. H., 1935. Suggestions to authors of papers submitted for publication by the United States Geological Survey: U. S. Geol. Survey, Washington, D. C. (For sale by Superintendent of Documents, Washington, D. C., 25c.)

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EARLY TERTIARY MARINE FAUNAS AND CONTINENTAL DRIFT*

J. WYATT DURHAM

ABSTRACT. Data on the geographic relationships of Recent marine faunas and of Eogene Eurasiatic Tethyan faunas of known spatial relationships are presented to serve as a standard of comparison for the evaluation of early Tertiary marine faunas in relation to "Continental Drift." It is concluded that the available data with respect to the temperature facies and geographic relationships of the Paleocene-Eocene marine faunas of the world indicate that no "Continental Drift," in the sense of Wegener and Du Toit at least, has occurred since late Cretaceous time.

INTRODUCTION

IN any evaluation of "Continental Drift" consideration must be given to its effect on the distribution of marine bottom dwelling invertebrates, for, if "drift" occurred, the relationships of land masses and seaways were different at various times in the past than at present. Consequently, the distributional pattern of the various regional marine faunas would be different than those now prevailing. Little attention has been given to this aspect of the "Continental Drift" problem, at least in the published literature. Another phase of the common versions of "Continental Drift" is that the poles occupied varying positions with respect to the land masses at different times during "drift" than they do now. This part of the problem bears upon the distribution of marine bottom dwelling invertebrates also, for the position of the poles furnishes the basic control for the distribution of the climatic zones of both the land and sea, and the climatic (referring to temperature) zones are in turn reflected in the marine fauna present in any specific area.

According to both Wegener (1924) and Du Toit (1937, 1944) the separation of the continents began in the late Meso-

* A contribution from the Museum of Paleontology of the University of California, Berkeley, California.

zoic, with the major movement occurring in the Tertiary, although Du Toit would have more early movement than Wegener. Nevertheless, Du Toit (1937, p. 204) feels that during the Oligocene the Caribbean region of the Americas was near enough to Europe and Africa for there to have been at that time a "close relationship" between the marine invertebrate faunas of the West Indies and the Mediterranean area. Du Toit further feels that these "connections" between the two areas did not become completely broken down until perhaps late Miocene time. Both Du Toit and Wegener, as well as Grabau (1940), agree that during the early Tertiary the North Pole was somewhere in the North Pacific with respect to the continental masses. Although there are differences of detail between the various versions of "Continental Drift," they all place the continental masses and the North Pole in such positions during the early Tertiary that there would have been marked changes (related to different temperatures) in the distribution of marine benthonic organisms as compared to that now in effect. It is the purpose of this paper to evaluate the early Tertiary faunas, more specifically those of the Paleocene-Eocene, and to determine whether or not their relationships are in accord with "Continental Drift." Inasmuch as variation in the position of the North Pole may have occurred independently of "Continental Drift" or vice versa, the two aspects of the subject will be considered independently.

MARINE FAUNAS AND CONTINENTAL POSITIONS

Distribution of recent benthonic organisms.—In evaluating later fossil faunas one has to use living faunas as a standard of reference. Interpretations, to be safe, have to be based on assemblages of organisms rather than on any single organism. In the present problem the distribution and areal relationships of the living benthonic organisms, and more particularly the shallow water ones, have to serve as the standard, for they are the type of organisms whose remains are commonly found as fossils.

The areal distribution and areal relationships of living shallow water faunas are controlled, among other things, by depth of water, temperature, presence of shorelines or shallow water for migration routes, currents, length of duration of free-swimming or planktonic larval stages, and closely con-

nected with the last factor, relative proximity of suitable habitats separated by deep water. One is not able to evaluate all the preceding factors in fossil faunas, but many of them can be determined more or less accurately by careful study.

Thorson (1950) has recently given much pertinent information on the larvae of marine invertebrates. He indicates that more than 70% of all Recent marine invertebrates have planktonic larvae, feeding on phytoplankton, with a pelagic life usually varying from two to four weeks duration in the summer, and one to three months duration in wintertime. This type of larvae is barely represented in arctic seas, is common in 55 to 65% of the species in boreal seas, and 80 to 85% of the great number of species in the tropics. Thus in the fossil record, assuming other conditions to be favorable, the faunas of seas where tropical temperatures prevailed should be fairly cosmopolitan. However, with respect to the transportation of larvae by currents across areas of deep water, Thorson, after discussing conditions under which some forms will extend their larval life, concludes (p. 18), "In most marine invertebrates (polychaetes, echinoderms, gastropods, lamellibranchs), from temperate as well as from tropical seas, the total pelagic larval life will, however, last only about 3 weeks... ." Thus it appears that about three weeks is the maximum duration of larval (transportable) life of a significant proportion of a fauna, although individual members of a fauna may have a much longer larval life. As the Gulf Stream moves across the North Atlantic its velocity varies from about 3 miles per hour along the American Coast to around ½ mile per hour as it approaches Europe. Out to about mid-Atlantic its speed is around 1¾ miles per hour. Thus in this current or in a similar one extending over oceanic deeps, a large proportion of a fauna would be able to migrate over a distance of about 900 miles as a result of the transportation of their planktonic larvae. However, those species with a larval life period of 3 months (the maximum given by Thorson) might be transported over a distance of about 4000 miles in the same current. Inasmuch as organisms with these long larval periods are apparently a minor element in the Recent faunas, it can be expected that they would also be a minor element in Tertiary faunas. The above data indicate that not much similarity can be expected in fossil faunas in areas over 900

miles apart if they were separated by oceanic deeps, and, conversely, if they were much closer together, even though separated by deeps, the faunas should have significant numbers of species in common, unless the current distribution was such as to render transportation in the necessary directions impossible.

The present day distribution of living Mollusca furnishes many useful data for comparison with the distribution of fossil faunas. Dall (1903) listed the fauna known at that time from the eastern coast of the United States, indicated the geographic distribution of the individual species, and also whether or not they occurred in European seas. Modern systematic concepts may have changed the ranges and identifications of some of the species listed by him, but nevertheless the forms listed by him as a single species are probably closely enough related to be significant in making biogeographic comparisons. Out of a total of 487 pelecypods and 1104 gastropods, Dall listed 81 pelecypods and 94 gastropods as also occurring in European waters. Sixty pelecypods and 43 gastropods are also reported either in the North Atlantic, Norway, the Arctic Ocean, or other northern areas, so the presumption is that their present distribution is continuous across the North Atlantic or Arctic regions to the more southerly European areas. There remain 21 pelecypods and 49 gastropods (2 gastropods are pelagic) whose Recent distribution is apparently discontinuous and whose distribution has to be explained by a more extensive distribution in the past, by accidental dispersion, or by transportation of the larvae by currents. It is also possible that some of the 60 pelecypods and 43 gastropods with an essentially continuous distribution may also have been distributed by one or more of the means of dispersal suggested for the species of restricted distribution.

In terms of percentages, the above data may be expressed thus:

	Pelecypoda	*Gastropoda*
Total identical species in Europe and southeastern United States	16.6%	8.51%
Species with a continuous distribution .	12.3%	3.89%
Species with a discontinuous distribution	4.3%	4.43%
Pelagic species		0.19%

For another type of comparison, the relationships of the molluscan faunas on the Atlantic and Pacific sides of Central America, where the two faunas have been separated since the middle Miocene, may be cited. Carpenter (1857, pp. 362-365) lists 35 identical species, 34 species which may be identical, 41 pairs of species separated by slight differences, and 26 pairs of analogous but distinct species between the Atlantic and Pacific sides of this area. In a much later work, Smith (1944, pp. xi-xii) lists 42 identical and 42 pairs of analogous species out of a total (in his lists) of 1297 species of gastropods, scaphopods, pelecypods, and chitons occurring in the Panamic (Pacific) fauna. These species are distributed among the various classes as follows:

		Identical	*Analogous*	*Pelagic*
Gastropoda	(834 species)	15 (1.79%)	18 (2.18%)	16 (1.92%)
Scaphopoda	(20 species)	0	0	0
Pelecypoda	(420 species)	10 (2.38%)	24 (5.71%)	0
Amphineura	(23 species)	1 (4.34%)	0	0

With respect to two areas separated by a long peninsula, the relationships of the Gulf of California fauna with that at San Diego may be cited. The Peninsula of Baja California, separating the Gulf of California from the San Diego area, is a narrow peninsula about 700 miles long, extending in a northwest-southeast direction. The faunal characteristics of the Gulf of California have been summarized in as much detail as our present knowledge of the area permits by Durham (1950a, pp. 4-6). Out of 96 gastropods and 97 pelecypods now living in the Gulf, 29 pelecypods and 10 gastropods are also found in the vicinity of San Diego. The molluscan fauna within the Gulf is much more closely related to the Panamic fauna than it is to that occurring in the vicinity of San Diego.

Many accurate data regarding the distribution of marine Mollusca along the West Coast of North America are available (Keen, 1937). From San Diego (33°N. lat.) to the entrance to Puget Sound (48°N. lat.) is a distance of nearly 1000 miles along an essentially north-south trending coastline. In February the average surface temperature of the ocean waters at the entrance to Puget Sound is about 8°C., the temperature at San Diego is about 15°C. These temperatures correspond to those at the Straits of Gibraltar and the middle of the west coast of Ireland or at 60°N. latitude in the North Atlan-

tic south of Iceland. Keen records a total of 1573 pelecypods, gastropods and scaphopods as occurring within the limits of this Pacific Coast area. One hundred and six out of 406 pelecypods and 173 out of 1167 univalves range throughout the entire distance, or 26% of the pelecypods and 14.8% of the gastropods.

Interesting data are also available from Keen's checklist regarding the fauna which occurs at San Diego (33°N. lat.). She records a total of 274 pelecypods and 748 univalves (gastropods and scaphopods) as living at this point. Of these, 58 pelecypods and 66 univalves range southward to Panama (8°N. lat.). Eleven pelecypods and 7 univalves (3 scaphopods) occurring here have a geographic range of 50° of latitude or more, while 30 pelecypods and 26 univalves have a range of 40° of latitude or more. Two pelecypods, *Saxicava arctica* and *S. pholadis*, are indicated as ranging from 8° to 72°N. latitude, or through a range of about 0° to 28°C., winter surface temperature. The gastropod *Crepidula aculeata* ranges from 17°N. latitude to 72°N. latitude, with winter surface temperatures from about 0°C. to 27°C., but it is to be suspected that it occurs only at greater depths (and thus cooler) in the southern part of its range. The above data from the Pacific Coast indicate that a significant proportion of a fauna from one area may have a wide latitudinal range and consequently a fairly wide tolerance of surface temperature variations (the organisms concerned may not have the same bathymetric distribution throughout all its geographic range and may thus compensate for the varying surface temperatures).

Further data on the relationships of the molluscan faunas of the Eastern Pacific are provided by Hertlein (1937). He recognizes about 29 species of molluscs and echinoids of tropical habitat as occurring along the western shores of the Americas and the adjacent islands, and in Polynesia and the Indo-Pacific. It would appear that some of these species must have been transported over distances of about 3000 miles or more over oceanic deeps in order to reach their present positions.

Keen (1941) has furnished data on Recent molluscs found along the Pacific shores of North America and in Japan, indicating that they have probably migrated from Japan along

the shallow water pathway of the Aleutian Islands and the mainland coasts. Her compiled list shows 37 pelecypods and 30 gastropods, out of a total fauna of nearly 2000 species in each area, that have been considered by various authors as identical species occurring on the West Coast and in Japan. Keen then tried to obtain specimens to check these identifications, with the result that she recognizes only 16-21 pelecypods and 12-22 gastropods as actually identical. Of these confirmed identifications, 3-5 pelecypods and 2 gastropods range from California to northern Japan. These long-ranging species are:

Clinocardium nuttallii (Conrad)
Gari californicus (Conrad)
Mytilus edulis Linnaeus
Pododesmus macroschismus (Deshayes)
Acmaea pelta Eschscholtz
Fusitriton oregonense (Redfield)

The Hawaiian Islands are an isolated group of true oceanic character, separated from the nearest mainland (Pacific Coast of North America) by about 3000 miles. All evidence indicates that they have been surrounded by "deep water" and have had no "shallow water" connections with any other region since the Cretaceous, and consequently the marine fauna there has a peculiar aspect, consisting largely of elements that were transported by oceanic currents. Edmondson (1941) has reviewed the general relationships of the fauna and notes nevertheless that it has some affinities with other regions. He notes that many of the gastropods are widespread through the South Pacific, East Indian and Indian Ocean areas, and that more than 20 species are also found in Japan. Ten of the species listed by Hertlein (1937) as occurring on the western coast of the Americas also occur in Hawaii. Four out of 96 species of stony corals now known from the eastern Pacific are also found in Hawaii (Durham and Barnard, unpublished manuscript). The existence of identical species of gastropods and stony corals in the Hawaiian Islands and the American mainland is in contrast to the condition reported for the pelecypods by Dall, Bartsch, and Rehder (1938) who state that there are no close relationships in this group of molluscs. It is to be suspected that the systematics in these

three groups in this area are on different planes of refinement.

The data presented in the preceding paragraphs, although not worldwide in extent, show that all reasonably large areas, even though separated by oceanic depths of considerably greater magnitude than those stated to have existed in the Atlantic region at the time continental drift was supposed to have occurred, have a number of identical or closely related species present, and indicate that the occurrence of a few identical or closely related species in early Tertiary faunas on both sides of the Atlantic is not necessarily to be taken as evidence of "drift."

Distribution of benthonic organisms in Tethys.—During the Eogene the evidence is clear that the Tethyan seaway extended all the way from the western part of the present Mediterranean through to India and Burma and, at times at least, apparently to the East Indies. As a reflection of this extensive east-west seaway, there is a great deal of faunal unity in deposits of the same age and facies throughout this region. The nummulitic foraminifera are widespread and abundant in this region from the western Mediterranean to the East Indies, particularly in the Eocene, with many species identical from one area to the other, a distance of over 6000 miles. Equally close rlationships exist in the Mollusca as long as similar facies are considered. Cox (1934) lists 10 out of 45 gastropods and 13 out of 54 pelecypods from the lower Eocene of India as also occurring in Europe. Of noteworthy interest is his record of the pelecypod *Euphenax jamaicensis*, originally described from Jamaica, in India and Somaliland. Vredenburg (1928) lists a total of 107 species and varieties of molluscs from the Indian Lower Nari series (lower-middle Oligocene). Of these, 43 (40.1%) are considered to be identical with, and 15 (14%) closely related to, species that occur in Europe, a distance of about 60 degrees of longitude or around 3000 miles. Vredenburg considers the Oligocene of Liguria (northwest Italy) as the closest analogy to the Lower Nari. From these Indian-European examples it can be seen that where there is a continuous shoreline or shallow water connecting distant areas of approximately the same latitude and temperatures a goodly percentage of the fauna will be the same.

Eocene marine faunas and "Continental Drift."—The most generally accepted version of "Continental Drift," or at least the one that paleontologists and biologists are most often concerned with, is that of Du Toit (1937). Many points not clear in the 1937 book are clarified, modified, or elaborated upon in a later paper (Du Toit, 1944).

A most unusual statement is reiterated in this last paper (1944, p. 145): "Geological evidence almost entirely must decide the probability of this hypothesis [Continental Drift] for those arguments based upon zoo-distribution are incompetent to do so." According to this statement paleontologic evidence has no bearing, either pro or con, with respect to the evaluation of "Continental Drift," yet Du Toit feels compelled to change many details of his version of the theory because of paleontologic evidence. In his 1944 paper Du Toit indicates (p. 153) that although the breaking up of the continents was initiated earlier, "actual rupture of the sial did not generally take place until the close of the Cretaceous, to pass through a series of climaxes during the Tertiary." Further (p. 155) he states, "The feasibility of double linkages, of an orogenic type, between Central America, Cuba and Spain, and Venezuela and Morocco respectively during the Cretaceo-Tertiary, happens to be a consequence of the scheme of drift proposed and is furthermore *independent* of *any paleontologic similarities between those four opposed continents*" (italics Du Toit's). He regards these bridges as having been raised up by "the rhythmic approach of the North American-Eurasiatic and the South American-African masses, but lowered by lengthwise tension under the westerly drift of the Americas as the meridional 'rift' of the Atlantic widened." He further states that the "shallow-water marine faunas of these latitudes show that for the earlier Tertiary the state amounting to a line of submarine ridges was undoubtedly attained..."

It is clear that Du Toit considered the Tethyan seaway to extend to the Caribbean area of the Americas, that the Americas were relatively close (compared to their present positions) to Europe and Africa, and that there were belts of orogenic movement, where uplift occurred, extending across the ancestral Mid-Atlantic, although he is not always clear with respect to the relative timing of these various events.

However, it appears that if "Continental Drift" occurred in any form approaching that of either Du Toit's or Wegener's version that either the ancestral Atlantic Ocean of the early Tertiary was narrow enough for many marine invertebrates to be transported across it, or that there was a migration route possible across the central Atlantic, or that both possibilities existed. Consequently there should have been considerable migration of members of the faunas of the areas that were close together, or isolated only by shallow water, or connected by "bridges" or submarine ridges. This migration and exchange of faunas would be indicated by analogous and identical species in greater numbers than now occur in the areas under consideration or in similar situations, yet the available faunal data from the American Eocene do not confirm this.

According to Du Toit, the Eocene of the Mississippi embayment and adjacent states should have been within the western extension of the Tethyan seas and consequently should have, by comparison with the situation existing between India and Europe cited previously, a considerable proportion of identical species, and a great number of analogous species, with the European Tethyan areas. However, when the content of the American middle and upper Eocene faunas of this area is examined one finds only 2 identical and 13 allied or analogous species listed between the Gulf Coast and Europe in the modern study of Palmer (1937) on the scaphopods and gastropods of the middle Eocene Claiborne fauna. Similarly in the upper Eocene Jackson fauna, Harris and Palmer (1946-1947) list only 1 identical (also listed in the Claiborne) and 6 related or analogous species, out of a total of about 352 species of pelecypods, gastropods, and scaphopods, as occurring in Europe. These figures, when converted to percentage, are less than those now existing between the same areas. It does not appear, even if these faunas were restudied by systematists who were looking for relationships, that the results obtained would indicate a closer relationship than that existing in the living faunas. Cooke (1924) reviewed the similarity of the American and European Eocene-Oligocene faunas and found that there were very few species in common —essentially the same results as are obtained in the more modern works cited above.

Rutsch (1941) has used the occurrence of several identical species of Mollusca in the Paleocene-Eocene of the Caribbean region and the "European-African Mediterranean" as an argument for "Drift," but when one considers that the total faunas of the intervals concerned must have numbered perhaps 2000 or more species, it does not appear that his particular arguments are valid. The number of identical or analogous species that he cites is not as great as the number which now occur in the same general regions.

Further data bearing on "Continental Drift" may be obtained from an examination of the Eocene faunas of the Pacific Coast. According to the concepts of Du Toit, as indicated above, the Tethyan seaway extended into the Caribbean. Furthermore, it is known that seaways extended across the Central American region from the Atlantic to the Pacific throughout most of the early Tertiary, up until about mid-Miocene time. Accordingly then, there should have been a reasonable number of molluscan species that migrated through this area to the Pacific Coast regions. As has been shown elsewhere (Durham, 1950b), tropical climates prevailed along the Pacific Coast of the Americas at least from Puget Sound south into Peru, and probably Chile, so that the temperature facies of this region was suitable for Tethyan faunas. However, when the western North American Paleocene-Eocene record is examined (Clark and Vokes, 1936), only 17 species are recorded from the entire Eocene as having any identity or close relationship with European Eocene faunas, and here the greatest relationship is with the Paris Basin Eocene rather than with the Tethyan faunas. For western South America, Clark (in Clark and Durham, 1946, p. 11) has concluded as follows, "The faunas of the lower, middle, and upper Eocene of Peru as listed by Woods and Olsson contain no molluscan species common to North America, Europe, or North Africa." This statement is in direct contrast to the relationship inferred by Rutsch (1941) from the occurrence of species (not identical, however) of the pelecypod genera *Raetomya* and *Venericardia* in Peru and in the Caribbean. It does not appear that species of a few genera should be given much weight in evaluating relationships when the remainder of the associated faunas militate against them.

From the preceding paragraphs it can be seen that the

relationships present in the Eocene faunas of the Mississippi embayment, eastern United States, and the Pacific shores of the Americas, as expressed in identical or analogous species with the Eocene faunas of western Europe and European Tethys, do not indicate any closer relationship with those areas than now exists. It would appear from the faunas that in the Eocene eastern North America was as far distant from Western Europe then as now, and, further, that there was no mid-Atlantic east-west trending chain of islands or submarine ridges for it would have furnished a migration route for a much greater number of identical or analogous species than are recognized in the two regions.

MARINE FAUNAS AND POLAR POSITIONS

Zonal distribution of Recent faunas.—Vaughan (1940, pp. 444-445) has recognized and defined the surface temperature zones of the oceans, recognizing five zones within each of the northern and southern hemispheres, with one, the tropical, being common to both. Within deeper water in the tropics all five temperature zones are also encountered from the surface to the bottom. These surface temperature zones of the oceans are distributed in more or less concentric belts around the north and south poles, with the detailed distribution locally being dependent upon currents, adjacent land masses, submarine topography, and other similar factors. Each of these zones usually grades gradually, one into the other, but nevertheless they have a characteristic fauna (Vaughan, 1940, p. 436), and can be recognized by that fauna, when it is taken as a whole (and not necessarily recognized by means of individual members of the fauna). Various organisms indicating temperatures, more particularly tropical temperature, have been listed and discussed in part elsewhere (Durham, 1950b). It appears that from our present day knowledge of marine faunas, the environment of fossil faunas, when they are of sufficient size and have been at least moderately well studied, can be determined with a moderate degree of precision.

Early Tertiary faunas and the poles.—According to both Wegener and Du Toit, during the early Tertiary the North Pole was situated in what is now the North Pacific Ocean. One version of these polar positions and the position of the

continents, in agreement with Wegener and Du Toit as far as can be ascertained, has been shown in polar projection elsewhere (Durham, 1950b, fig. 1). Whether or not this version is precisely correct, the general effect on the distribution of the temperature zones of the earth would have been the same. The present North Pacific Ocean, Kamchatka, and adjacent northeastern Siberia would have been within the Arctic Circle, while on the western shores of the Americas the equator would have been someplace near the latitude of San Diego. In the East Indies the equator would have been south of its present position and in Europe it would have passed some place in the vicinity of northern Italy. If the temperature belts of the earth maintained their present zonal distribution with respect to the poles, then this proposed early Tertiary position of the poles should be subject to confirmation by the character of the marine faunas found in numerous critical areas.

The Eocene faunas of California, Oregon, and Washington, and the Oligocene faunas of Washington have been fairly well studied, and it is apparent during the Eocene that the tropics extended northward along this coast to some place north of 49°N. latitude, while during the later Oligocene the temperature at the same latitude gradually cooled off to about 18°C. (Durham, 1950b). During the Eocene numerous tropical gastropods and pelecypods, large foraminifera, reef corals, and other organisms were living in Washington. The faunas were highly varied, another characteristic of the tropics. A moderate amount of data is also available on Kamchatka (Ilyina, 1939; Pleshakov, 1939; Slodkewitsch, 1938). Here, however, instead of the boreal faunas which might be expected under the postulated Eocene-Oligocene polar positions of continental drift, we find Mollusca indicating warmer temperatures than now prevail in the same area. The genera *Turritella*, *Macrocallista*, and *Crassatellites* are well represented in the Eocene-Oligocene faunas of this area, and these genera today are typical of tropical to warm temperate faunas. Furthermore species such as *Turritella uvasana*, *Turritella* cf. *uvasana*, *Turritella* cf. *blakeleyensis*, *Macrocallista pittsburgensis*, and *Crassatellites* aff. *washingtoniana* of the Pacific Coast Eocene-Oligocene faunas are reported as occurring, along with other less significant identical or re-

lated species, in Kamchatka. This is a relationship similar to that reported by Keen (1941) as occurring between western North America and Japan. It appears highly improbable that such a relationship would have existed during the Eocene-Oligocene if the areas had been more distant geographically, and if the polar region had intervened in the manner postulated by Wegener and Du Toit.

This relationship and the tropical to warm temperate character of the faunas is supplemented by the poorly known marine Eocene faunas from the south side of the Alaska Peninsula (160°W. long.). The poor material obtained from Stepof (or Stepanof) Bay was described by Dall (1904) and includes, among others, a large *Venericardia* of the *planicosta* type, *Acila*, *Macrocallista*, *Ostrea*, *Mesodesma*, *Clavelithes?*, *Rimella?*, *Cassis*, *Ampullina?*, *Cerithium*, *Chrysodomus*, and *Phacoides*. Some 32 genera in all are recorded from this area, many of them being represented only by fragments or molds. Nevertheless there are enough significant elements in it to indicate at least subtropical or warm temperate affinities.

Elsewhere in the world the Eocene faunas indicate a similar picture, with faunas of tropical and warm temperate aspect occurring far outside the present geographical limits of the tropics as well as within the present tropics. The Eocene faunas of Peru (Olsson, 1928, 1929, 1930) are distinctly tropical in nature with abundant large foraminifera, various strombid gastropods, volutids, *Ficus*, *Cypraea*, *Conus*, *Spondylus*, large Venericardias, corals, and other characteristic tropical elements. Similarly, the upper Eocene fauna of Nanggulan, Java (Martin, 1914, 1931) is obviously tropical and must have lived in waters very similar to those now prevailing in the same region. In New Zealand, the faunas of the Bartonian and Tahuian stages (Finlay and Marwick, 1941; Allan, 1926) on South Island (around 44°S. lat.) clearly indicate a tropical climate. The faunas include *Crassatellites*, *Priscoficus*, *Notoplejona*, *Venericardia*, *Galeodea*, *Euspinacassis*, *Marginella*, *Aturia*, *Architectonica*, *Cucullaea*, *Rapana*, *Acteon*, *Conus*, many endemic molluscan genera of tropical aspect, and large foraminifera such as *Assilina*, *Discocyclina*, and *Asterocyclina*.

Chapman (1940) has recorded *Discocyclina*, *Pellatispira*, *Asterocyclina*, *Aktinocyclina*, *Nummulites*, *Operculina*, and

other large foraminifera from northwest Australia, clearly indicating well developed tropical seas in this area in the Eocene.

From the island of Kyushu, southern Japan (about 33°N. lat.), Nagao (1928) has recorded *Nummulites, Discocyclina, Nerita,* and *Siphonalia.* This list, although small, is adequate to indicate an Eocene age and a tropical environment.

The faunas of the Ranikot, Laki, and Khirthar of northwest India are certainly tropical in character, with numerous *Nummulites* and other large foraminifera, large *Venericardia, Cypraea, Gisortia, Velates, Architectonica, Hipponyx, Turritella, Rostellaria, Terebellum, Ficus, Harpa, Crassatellites, Spondylus,* and numerous other molluscan genera of similar requirements. In Europe, the rich Eocene faunas (Furon and Soyer, 1947) of the Paris Basin (49°-50°N. lat.) clearly indicate tropical temperatures. The faunas include a few reef coral genera, a number of echinoids, bryozoa, brachiopods, and the following molluscan genera: *Corbula, Donax, Tapes, Marcia, Meretrix, Pitar, Tivelina, Miocardia, Isocardia, Chama, Corbis, Crassatellites,* large *Venericardia, Anadara, Barbatia, Pinna, Avicula, Spondylus, Plicatula, Nerita, Velates, Ampullina, Xenophora, Hipponyx, Architectonica, Turritella, Mesalia, Cerithium, Ficus, Melongena, Voluta, Lyria, Harpa, Conus, Terebra, Campanile, Potamides, Rostellaria, Terebellum, Cypraea, Gisortia,* and others. The surface temperatures in February would not have been less than 20°C. in the Paris Basin.

Paleocene faunas are known from the Volga Basin (around 50°N. lat. and 45°E. long.). According to Davies (1934, pp. 79-80) the fauna includes, among others, *Cucullaea, Lucina, Crassatellites, "Cytherea," Corbula,* and *Turritella,* each represented by several species. In the Crimea (45°N. lat.) Davies (*loc. cit.*) indicates that Paleocene marls with *Cucullaea* are overlain by nummulitic marls. The fauna from the last named would indicate purely tropical conditions while that from the more northern localities would appear to be of a marginal tropical character.

The Paleocene (?) fauna (Ravn, 1922) of Spitzbergen (78°N. lat.) contains several species of *Cyrena* with strong Paris Basin affinities, *Dosiniopsis, Lucina, Callista,* and *Solenocurtus.* This fauna appears to represent considerably warmer temperatures than now prevail in this area, perhaps

a winter surface temperature between 5° and 8°C. The marine Paleocene-Eocene fauna (Ravn, 1933) from the vicinity of Cape Dalton (about 69°N. lat.), East Greenland, generally corroborates the evidence from Spitzbergen. Ravn lists *Cyrena* (abundant), *Donax*, *Glandulina*, and *Psammobia?* among the 20 invertebrate genera recorded from the Cape Dalton beds, and also notes that a number of other gastropod genera occur, both ornamented and unornamented, but that he had been unable to prepare them so that they could be identified. The genus *Glandulina* is a terrestrial gastropod belonging to a family all of whose living members are restricted to regions of warm temperate or tropical climate. It would appear that the marine winter surface temperatures in this area must have been at least above 10°C.

Along the east coast of North America, there is a general lack of marine fossiliferous deposits of Eocene age north of New Jersey (40°N. lat.); consequently an accurate determination of the northward limits of the Eocene tropics cannot be made. However, the Eocene faunas (Whitfield, 1891; Cooke and Stephenson, 1928) of New Jersey contain, among others, the following genera of Mollusca: *Cucullaea*, large *Venericardia*, *Crassatellites*, *Ficus*, *Conus*, *Spondylus*, *Plicatula*, *Pteria*, *Cypraea*, *Voluto*, *Turritella*, *Xenophora*, *Architectonica*, *Mesalia*, and nautiloids. These genera are adequate to indicate that the winter surface temperatures were at least 20°C. or higher.

At Luderitz Bay in South Africa (about 26°30′ S. lat. and 15° E. long.) a very significant Eocene fauna (Boehm, 1926) occurs. Although only 41 species of molluscs are known, they include a nautiloid, the genera *Raetomya*, *Turritella*, *Noetia*, *Pseudoliva*, *Sconsia*, *Voluta*, *Vexillum*, *Melongena*, *Mactra*, *Spisula*, *Lithodomus*, *Leda*, *Ostrea*, and *Perna*. This region today has a winter temperature only slightly below 20°C. and the above fauna would indicate that it was at least as warm during the Eocene. Correspondingly, Chapman (1930) has reported middle or upper Eocene *Discocyclina* and *Nummulites* from Birbury (33°30′ S. lat., 26°30′ E. long.), South Africa, again indicating a tropical environment. Thus the available evidence would indicate that all of Africa was within the tropics during the Eocene.

Eogene marine faunas appear to be largely lacking in

southern South America. The Patagonian formation or stage of Patagonia and its fauna have been partially known since the days of Darwin. Ortmann (1902) and Wilckens (1921) have reviewed the fauna in considerable detail, but its precise age has been uncertain. Simpson (1940) has reviewed the age of the underlying and overlying beds and concluded (p. 695) that the Patagonian is probably of earliest Miocene age. The next older marine beds are known as the Salamanca formation. The fauna of this formation has been studied by Feruglio (1938), while its age has been reviewed by Simpson (*op. cit.*). Simpson concluded that the Salamanca formation was probably of early Paleocene age. Feruglio felt that it was probably latest Cretaceous. If the *Exogyra* reported by Feruglio and others is correctly assigned generically, it appears more probable that Feruglio's age assignment is correct. The interval of most interest to the present paper falls between the Salamanca and the Patagonian but lacks marine fossils; thus we can only infer from the fauna of these two formations what the fauna and temperature facies of the intervening period was. According to Feruglio the Salamanca contains in its relatively sparse fauna the following molluscs: *Crassatellites, Dosinia, Meretrix, Corbula, Turritella* (several species), and "*Nautilus.*" The fauna appears adequate to indicate at least marginal tropical conditions. The known fauna of the Patagonian is much larger and includes the following significant molluscs: *Cucullaea, Perna, Crassatellites, Meretrix, Dosinia, Corbula, Venus, Crucibulum, Turritella* (several species), *Dolium, Ficus, Voluta* (several species), and *Bulla.* Wilckens (1916) has shown that a similar fauna is present on Seymour Island, still farther south. It appears adequate to indicate a temperature of 20°C. By inference from these two faunas the intervening interval should also have been at least as warm. It appears that the 20°C. isotherm was probably some place between 50° and 60° S. latitude in this part of the world during the early Tertiary.

In the preceding paragraphs, the temperature requirements of selected critical marine faunas scattered around the world have been discussed. Many more such faunas from other localities could have been treated in a similar manner. For instance, the entire Eogene "nummulitic facies" of Davies (1934) is of tropical and subtropical character. The localities

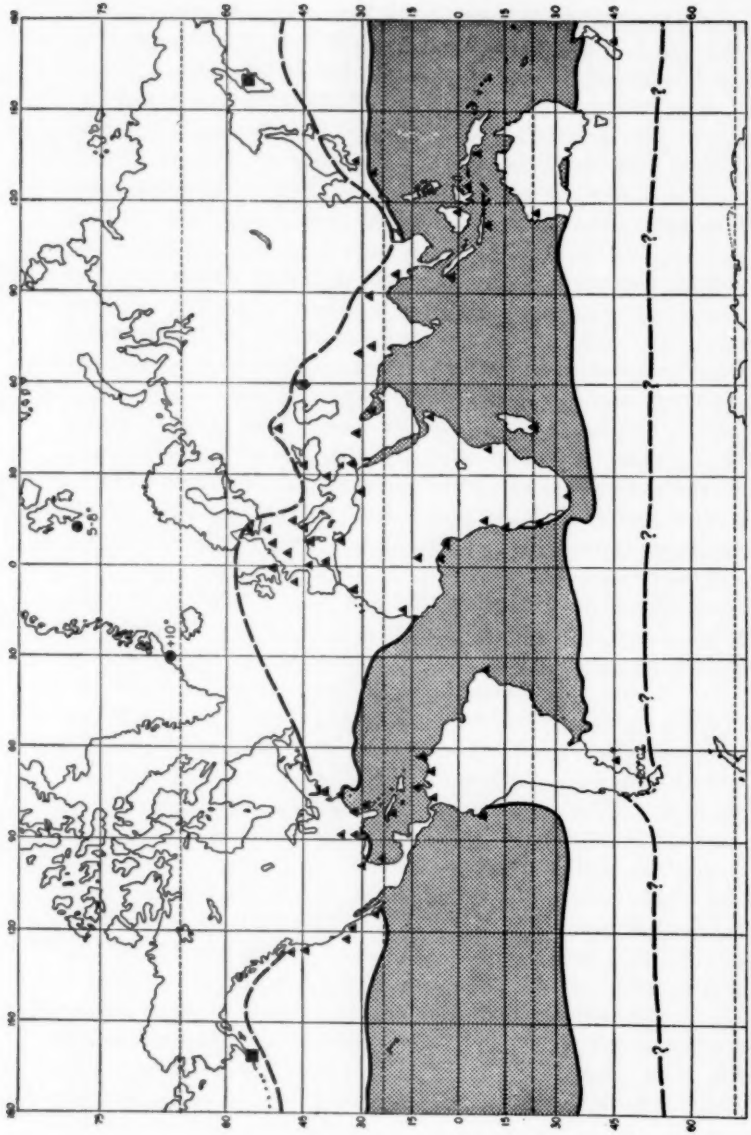
-L E G E N D-
▲ Tropical Faunas. ■ Significant Warm Temperate Faunas. ● Other Significant Faunas.
—Boundary of Present Tropics (February)—Boundary of Paleocene-Eocene Tropics.
EQUATORIAL SCALE
0 1000 2000 3000 MI.
(MERCATOR'S PROJECTION)

Fig. 1

presented in this paper, as well as other localities where a Paleocene or Eocene fauna of tropical or subtropical character is found, are plotted on figure 1. The available data from marine faunas indicates that the tropics of the early Tertiary extended much farther towards the polar regions at that time than at present. Further, the distribution of warm temperate and tropical faunas around the North Pacific indicates that at no time during the Paleocene-Eocene could the North Pole have been in the position in the North Pacific where Wegener and Du Toit indicate that it should have been according to "Continental Drift." Finally, the world-wide distribution of the tropical and subtropical marine faunas of this age indicate that the poles must have been in approximately the same position then as now. The data presented by Chaney (1940, 1947) with respect to the distribution of terrestrial floras of early Tertiary age are in full accord with the marine evidence. Similarly, Simpson (1943) has indicated that the distribution of terrestrial mammals during the Tertiary is not in accordance with "Continental Drift."

From the study of the climatic evidence afforded by the Tertiary marine faunas on the Pacific Coast (Durham, 1950a), as well as on a world-wide basis, it appears that during the early Tertiary, probably continuing through from at least the late Mesozoic, tropical climates were much more widespread then than now, and that there was gradual cooling off through the Tertiary until the Pleistocene glaciation came into effect. As a corollary to this it is apparent that the present restricted tropical climatic belts of the earth are abnormal, and that the normal (geologically speaking) situation is for them to be at least as widespread as they were during the Eocene.

Summary

In summary, the available data on the distribution of Recent and Paleocene-Eocene marine faunas indicate the following with respect to "Continental Drift":

1. The occurrence of a few identical or closely related species in early Tertiary faunas of areas now on opposite sides of the Atlantic is not evidence of "Drift," for similar occurrences are present in the Recent faunas of widely separated areas.

2. Along the known extension of the Tethyan seaway from India to Europe, 40.1% of the lower-middle Oligocene fauna of India is identical with, and an additional 15% are closely related to, species that occur in Europe at that time, some 3000 miles distant. This furnishes a standard of reference for comparison of faunas of areas such as the Caribbean and the European Tethys—areas which were supposedly connected by similar seaways.
3. There are very few identical or closely related species in the Paleocene-Eocene of the Caribbean-Gulf of Mexico area and the European Tethys areas, indicating that these areas were neither closely approximated nor connected by any cross-Atlantic chain of islands or submarine ridges.
4. From the relationships of the Paleocene-Eocene faunas of the Americas and Europe-Africa, the two regions appear to have been as far distant from each other during that interval as at present.
5. The distribution of tropical and warm temperate faunas in the North Pacific during the Eocene-Oligocene, and the relationships of faunas of similar age in Kamchatka and along the Pacific Coast indicate that the North Pole at that time did not occupy a position in the North Pacific similar to that postulated by Wegener and Du Toit.
6. The distribution of tropical marine faunas during the Paleocene-Eocene indicates that the North Pole must have occupied the same position then as now, thus negating this aspect of "Continental Drift" during the Tertiary.
7. Tropical climates extended much farther towards the poles during the Paleocene-Eocene than at present, and it is suggested that this is the normal condition for the earth rather than the present relatively narrow tropical climatic belt.

In conclusion, it appears that the temperature facies and geographic relationships of the Paleocene-Eocene marine faunas of the world indicate that no "Continental Drift," in the sense of Wegener and Du Toit at least, has occurred since at least late Cretaceous time.

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FRESHWATER MOLLUSCAN FAUNA FROM AN UPPER CRETACEOUS PORCELLANITE NEAR SAGE JUNCTION, WYOMING *

TENG-CHIEN YEN

ABSTRACT. A nonmarine molluscan fauna represented by 20 species in 14 genera and 12 families is described for the first time from an Upper Cretaceous bed of porcellanite-like lithology. The dominant element of pulmonates in the assemblage indicates a shallow and still-water facies. The admixture of 5 species, or 25 per cent of the fauna, of land snails may mean the former presence of a woodland near the fossil site. The occurrence of 8 sinistral species out of 18 species of gastropods, or nearly 44 per cent, may be attributed to such factors as the mineral content of the water in which the aquatic forms lived, perhaps resulting from the peculiar type of local soil, high in volcanic ash, that was in part redeposited later on to form the porcellanite-like rocks.

INTRODUCTION

THIS paper reports the occurrence in a porcellanite-like rock of a freshwater molluscan fauna, and it is believed that it is the first such record. All previous reports of fossil animals relate to marine forms and it had seemed necessary to assume that all the porcellanites were of marine origin. Such rocks as the Mowry formation and the Aspen formation have a wide distribution over the Rocky Mountain States and form an important part of the early Upper Cretaceous deposits. Rubey (1929) and Reeside and Weymouth (1931) first noted the pyroclastic character of the porcellanite rocks of the Mowry and Aspen formations. Reeside and Weymouth (1931) gave an account of the marine invertebrates, Cockerell (1919) of the fish, and Brown (1933) of the plant remains. The bed containing freshwater invertebrates was discovered by Rubey and McLaughlin in approximately the center of Sec. 7, T. 21 N., R. 119 W., near Sage, Lincoln County, Wyoming. The fossil site is about 1500 feet west-northwest of the old abandoned coal mine at Sage, and about 900 feet north of U. S. Highway 30 N. Several collections were

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subsequently made from this locality in 1949 and 1950, the results of which are herein presented.

In completing this paper, I want to express my thanks to W. W. Rubey and W. F. Foshag for their expert information, through personal discussion, on lithologic features of this unusual type of rock; to both John B. Reeside, Jr., and W. W. Rubey for their valuable information on the stratigraphic position and other related problems of this fossil bed, and for their kind assistance in the field, by which my work was very much benefited. I want, moreover, to thank both of them for their critical reading of this manuscript, resulting in improvement of the contents.

STRATIGRAPHIC POSITION AND LITHOLOGIC FEATURES OF THE BED

The fossil-bearing bed occupies a stratigraphic position in the lower part of a 3400-foot unit, at present unnamed, of early Upper Cretaceous rocks. It is approximately equivalent to Beds L1, L2 and L3, referred to in one of my recently published papers (U. S. Geol. Survey Prof. Paper 233-A, Part 2), which beds are exposed about 5½ miles north of the present locality. The present bed is about 1½ feet thick and richly fossiliferous, though the fossils are mostly imperfectly preserved. It is underlain by a bed of light gray, calcareous sandstone about 2 feet thick, which also yields an assemblage of freshwater mollusks. This sandstone bed is in turn underlain by a 1½-foot bed of conglomeratic sandstone.

The matrix consists of medium to light gray, slightly calcareous, hard porcellanite-like rock. The fractures of the rock generally show a tendency to be concave, and the ground mass is formed by fine siliceous volcanic ash, with some carbonates, fine clay and occasional grains of angular quartz. The ash was probably deposited in a body of water either by direct fall from the air or by reworking and stream transportation. When the calcareous matter of the molluscan shells was replaced by siliceous material from the ash, the molluscan remains became more or less inseparable from the matrix, and, further, the shells were much distorted by pressure in the process of fossilization, with the result that they are now in a poor state of preservation.

BIOTIC COMPOSITION AND ITS BEARING ON HABITAT CONDITIONS

The bed yields the following assemblage of molluscan species, in addition to some ostracodes, imperfectly preserved plant leaves and fish bones:

Unionidae
Unio cf. *U. aldrichi* White
Sphaeriidae
Sphaerium cf. *S. recticardinale* Meek and Hayden
Helicinidae
Helicina? sp. undet.
Cyclophoridae
Palaeocyclotus? sp. undet.
Pseudarinia pupilla, n. gen. and sp.
Pseudarinia convexa, n. sp.
Valvatidae
Valvata sp. undet.
Viviparidae
Viviparus cf. *V. priscus* (Tausch)
Pleuroceritidae
Goniobasis sp. undet.
Amnicolidae
Charydrobia sp. undet.
Sagia physoides, n. gen. and sp.
Sagia elongata, n. sp.
Sagia amnicoloides, n. sp.
Sagia globosa, n. sp.
Ellobiidae
Zaptychius cf. *Z. haldemani* (White)
Zaptychius sp. undet.
Physidae
Physa cf. *P. usitata* White
Physa cf. *P. kanabensis* White
Planorbidae
Anisopsis cf. *A. minuta* Yen
Helminthoglyptidae
Mesoglypterpes sagensis, n. gen. and sp.

In analyzing the above assemblage of molluscan species, it may be noted that: first, pulmonates constitute about 30 per cent of the total number of gastropod species; second, about 25 per cent of the gastropods are terrestrial species;

and third, about 45 per cent of the gastropod species are sinistral forms.

The dominant element in the assemblage, 5 species of aquatic pulmonates, clearly indicates a shallow- and still-water facies for the enclosing deposit. The aquatic forms also include 5 species of rissoid snails. This combination clearly also indicates the presence of a rich growth of both emergent and submergent plants, necessary to the existence of these gastropods. An admixture of 5 species of terrestrial gastropods in the assemblage, some of which would have found a favorable habitat in the roots of trees and in moist, shady areas, may mean the presence of a woodland nearby. Such snails were probably brought into the water by heavy rainfalls or through small streams in the woods.

The presence of nearly 50 per cent of sinistral forms of gastropods provides a highly interesting, though problematical, feature in the present assemblage. Sinistrality among the gastropods has been explained as caused by electric current flowing in the opposite direction to the embryonal rotation, or by the crowding of the embryos in the oviduct in the early stages of their existence. It is believed, however, that the chemical environment may have some influence in producing sinistral forms of snails, i.e., where the composition of the water and soil may be of an unusual type.

Sinistral coiling of the shell, as is well known, in some forms is only an abnormal occurrence of a normally dextral species, and in some forms is a persistent character of generic importance. *Pseudarinia* and *Sagia* may be taken as of this later category, for the presence of numerous individuals gives sufficient evidence that they are normally sinistral genera of gastropods.

Indeed, it is a very rare occurrence to have 8 species, in 3 genera, of sinistral gastropods in a single fossil bed. Moreover, these sinistral forms have so far not been found in contemporaneous beds near the present locality, nor have related forms been found in beds at higher and lower levels. It may be assumed therefore that the presence of these sinistral species is to be attributed to some such factors as the composition of the water and the presence of a peculiar type of local soil derived from volcanic ash, in part redeposited to form the porcellanite-like rock in which the fossils are found.

A considerable difference is revealed by a comparison of the molluscan fauna of the present bed with that of an approximately contemporaneous bed exposed about 5½ miles to the north. This difference, however, results from the presence of more sinistral elements and of species of terrestrial habitat included in the present assemblage. Apart from these new elements, the beds in both localities yield resembling species of *Valvata*, *Zaptychius*, *Anisopsis* and *Physa*. Some of these in the present bed were probably indigenous, as is demonstrated by the fossils in an underlying bed—a light gray calcareous sandstone about 2 feet thick—which contains the following species of mollusks (the poor state of preservation does not permit specific identifications).

Unio sp. undet.
Pisidium sp. undet.
Amnicola sp. undet.
Zaptychius sp. undet.
Physa sp. undet.

Such an assemblage of molluscan species not only suggests what were the indigenous elements in the present bed but also its harmony with the contemporary beds in the vicinity. No fossils have so far been found in the beds immediately above the present one, but a sandstone occurs about 350 feet higher stratigraphically in the same section that contains the following species of mollusks:

Pisidium sp. undet.
Viviparus sp. undet.
Amnicola sp. undet.
Physa sp. undet.

Although specific identifications of the poorly preserved forms mentioned above are not possible at present, these forms resemble the congeneric species from the related beds exposed in the vicinity. Such occurrences clearly indicate that many of the species in the present bed were remnants of a local fauna which continued to survive over the same area at a later age.

The additional elements of sinistral and terrestrial gastropods in the present bed no doubt give us a more complete knowledge of the non-marine molluscan fauna then in existence,

and it was perhaps a more typical one of the time. The occurrence of such a fauna may imply that the fossil site was farther from the coastal line in an environment where the inland water was much less influenced by the sea. It may also imply that the environmental conditions were much affected by the contemporaneous volcanic action and that, however brief the period might have been, mutation of the organic beings underwent some drastic changes.

AGE OF THE DEPOSIT

The present fossil bed occupies a stratigraphic position in the lower part of a 3400-foot unit of early Upper Cretaceous rocks. It is about 250 feet stratigraphically higher than Bed L-5, the fossil contents of which I have recently reported (U. S. Geol. Survey Prof. Paper 233-A, Part 2). In discussing the age of Bed L-5, I have suggested, on the basis of the non-marine invertebrate fauna, that it may represent post-Cenomanian deposition. If this assumption be correct, the present fossil-bearing bed may be of somewhat younger age than the Cenomanian.

As is shown under the previous heading, the molluscan species in the present bed are essentially in harmony with those of Beds L-5, and they are also similar to those of a bed underlying the present one. It may be noted, further, that a shale bed, 700 feet stratigraphically higher than the present one and exposed in a road cut at Sage Junction, contains the following species of mollusks:

Unio sp. undet.
Mesoneritina sp. undet.
Lioplacodes cf. *L stachei* (White)
Parateinostoma cf. *P. altispira* Yen
Zaptychius sp. undet.
Physa sp. undet.

This assemblage clearly reveals its similarity to that of Bed L-5, and represents the highest stratigraphic position at which Cretaceous invertebrates have been found for many miles. This discovery is of considerable importance, as it indicates that the molluscan elements form a harmonious fauna through beds aggregating about 1000 feet of stratigraphic range.

SYSTEMATIC ACCOUNT OF THE MOLLUSCAN SPECIES

Family Unionidae

Unio cf. *U. aldrichi* White

Plate 1, figs. 1-3

Unio aldrichi White, Hayden Survey 12th Annual Rept., Part 1, p. 62, plate 29, fig. 2 for 1878 (1883).

The definite features observable in the imperfectly preserved specimens in this collection are a prominent umbonal ridge and well-developed concentric lines over the umbonal area, by which features they may be related to *Unio aldrichi*.

Figured specimens: U.S.N.M. 108148, 108150, 108152.

Family Sphaeriidae

Sphaerium cf. *S. recticardinale* Meek and Hayden

Plate 1, fig. 4

Sphaerium recticardinale Meek and Hayden, Proc. Acad. Nat. Sci. Philadelphia, Vol. 12, p. 176, 1860.

Several specimens resemble *S. recticardinale* in general outline, but are smaller in size. They may possibly represent a distinct species, but this can be established only on better preserved specimens.

Figured specimen: U.S.N.M. 108153.

Family Helicinidae

Helicina? sp. undet.

Plate 1, fig. 45

Two imperfectly preserved specimens possess some shell features of *Helicina* in the broad sense. They are undoubtedly of terrestrial origin, and the presence of an umbilical callosity, shown in one of the broken specimens, differentiates it from the common helicoid type of gastropods. Better preserved specimens will facilitate a full description of this distinct species of the land operculates.

Figured specimen: U.S.N.M. 108155.

Family Cyclophoridae

Paleocyclotus? sp. undet.

Plate 1, fig. 46

A few imperfectly preserved specimens of small size, with 3 to 4 angulately tabular whorls and widely open umbilicus, may be provisionally assigned to a distinct group resembling

Paleocyclotus Fischer, a genus described from the Bartonian beds in Europe. In addition to both geological and geographical separation from *Paleocyclotus*, the present form has a much more depressed spire and more closely coiling whorls.

Figured specimen: U.S.N.M. 108156.

Pseudarinia Yen, new genus

Shell sinistral, of minute size, narrowly oblong in outline, having an elevated spire and descending body whorl. Whorls few, more or less shouldered, scarcely to strongly convex, bearing faint sculpture and separated by a well impressed suture. Aperture descending in front, ovately oblong in outline, having peristome slightly reflected. Umbilicus perforate and excavated at the base.

Genotype: *Pseudarinia pupilla* Yen.

The new genus resembles some genera usually assigned to *Diplommatininae* of this family. It may be compared with *Arinia* H. and A. Adams and *Palaina* Semper; but it differs from both of them by having a narrowly oblong outline of shell, a distinct shoulder on the whorls, less circular aperture and prominently excavated base of the body whorl.

Pseudarinia pupilla Yen, n. sp.
Plate 1, figs. 23, 29-30

Shell sinistral, perforate, and cylindrically elongate in outline, less than 3 mm. in height, having an elevated spire and descending body whorl, the former greater than the latter, as shown in a more perfectly preserved specimen. Whorls gradually increasing in size, scarcely convex and slightly shouldered. Suture well impressed. Aperture ovately oblong, descending in front and excavated at the base.

Altitude of shell	2.0	2.0
Width of shell	0.6	0.8
Height of aperture	–	0.7
Width of aperture	–	0.4
Number of whorls	5	5

The species is characterized by its pupoid outline of shell, scarcely convex and slightly shouldered whorls, and ovately oblong shape of aperture. The peristomal margin appears to be thickened within, but it is not definitely traceable on the available specimens.

Holotype: U.S.N.M. 108158; Figured paratypes: U.S.N.M. 108159, 108161d; Unfigured paratypes: U.S.N.M. 108161a, b, c, e.

Pseudarinia convexa Yen, n. sp.
Plate 1, figs. 21-22, 24

Shell sinistral, perforate, and ovately oblong in outline, having an elevated spire, tapering toward the apex, and descending body whorl reducing at the base. Whorls strongly convex, obtusely shouldered, gradually increasing in size of the early ones and more rapidly in the later ones, which are separated by deeply impressed sutures. Body whorl descending, slightly angulated on the shoulder and attenuated at the base, which may indicate an aperture of subovate outline.

Altitude of shell	2.5	2.0
Width of shell	1.2	1.1
Height of aperture	–	–
Width of aperture	–	–
Number of whorls	5	4+

PLATE 1

Figs. 1-3. *Unio* cf. *U. aldrichi* White—Fig. 1, X 1 and Figs. 2-3, X 2.
Fig. 4. *Sphaerium* cf. *S. recticardinale* Meek and Hayden, X 10.
Figs. 5-6. *Viviparus* cf. *V. priscus* (Tausch)—Fig. 5, X 2 and Fig. 6, X 4.
Figs. 7-9. *Goniobasis* sp. undet.—Figs. 7 and 9, X 4 and Fig. 8, X 10.
Fig. 10. *Sagia physioides*, n. gen. and sp., X 2.
Fig. 11. *Sagia elongata*, n. sp., X 4.
Fig. 12. *Sagia amnicoloides*, n. sp., X 10.
Figs. 13-14. *Sagia globosa*, n. sp., X 10.
Figs. 15-18, 20. *Zaptychius* sp. undet., X 10.
Fig. 19. *Zaptychius* cf. *Z. haldemani* (White), X 10.
Figs. 21-22, 24. *Pseudarinia convexa*, n. gen. and sp.—Fig. 21, X 5 and Fig. 24, X 10.
Figs. 23, 29-30. *Pseudarinia pupilla*, n. sp.—Fig. 23, X 5 and Figs. 29-30, X 10.
Figs. 25-28. *Physa* cf. *P. usitata* White—Figs. 25-26, X 2 and Figs. 27-28, X 1.
Figs. 31-33. *Physa kanabensis* White, X 4.
Figs. 34-39. *Anisopsis* cf. *A. minuta* Yen—Fig. 34, X 5 and Figs. 35-39, X 10.
Figs. 40-43. *Mesoglypterpes sagensis*, n. gen. and sp.—Figs. 40, 42-43, X 4 and Fig. 41, X 2.
Fig. 44. *Charydrobia* sp. undet., X 2.
Fig. 45. *Helicina?* sp. undet., X 2.
Fig. 46. *Palaeocyclotus?* sp. undet., X 2.
Fig. 47. *Valvata* sp. undet., X 10.

This species differs from *Pseudarinia pupilla* by its ovately oblong outline of shell and more strongly convex whorls, with more prominent shoulders. All the specimens available are embedded in the matrix and none of them shows the apertural features.

Holotype: U.S.N.M. 108162; Figured paratypes: U.S.N.M. 108163, 108164, 108165; Unfigured paratypes: U.S.N.M. 108167a,b.

Family Valvatidae
Valvata sp. undet.
Plate 1, fig. 47

A few young individuals represent this form in the assemblage. It is possibly related to *Valvata praecursoris* White, but the specific identification cannot be established, as the specimens available are partly embedded in the matrix.

Figured specimen: U.S.N.M. 108166.

Family Viviparidae
Viviparus cf. *V. priscus* (Tausch)
Plate 1, figs. 5-6

Paludina priscus Tausch, Abhandlungen der K. K. Geol. Reichsanstalt, Band XII, Heft 1, p. 11, plate 1, figs. 40, 41a,b, 1886.

Several imperfectly preserved specimens represent this form in the collection. The best example has the last two whorls preserved and resembles closely in size and outline of shell *Paludina priscus* (Tausch), which was described from an Upper Cretaceous bed exposed near Ajka, in Western Hungary. Definitely specific identification will have to be established on more perfectly preserved specimens.

Figured specimens: U.S.N.M. 108169a, 108169b.

Family Pleuroceratidae
Goniobasis sp. undet.
Plate 1, figs. 7-9

About a dozen specimens, including a few apparently immature ones, seem to represent a smooth form of *Goniobasis*. The species resembles *Melania heberti* Hantken (Tausch, 1886, p. 7, plate 1, figs. 13-15). However, it is much smaller in size and has a narrower outline of shell.

Figured specimens: U.S.N.M. 108171a, 108172, 108173a.

Family Amnicolidae

Charydrobia sp. undet.

Plate 1, fig. 44

A number of specimens, which may be recognized by their small size (about 5 to 6 mm. in altitude of shell) and rather stout outline of shell, may represent a form of *Charydrobia stachei*—a genus which has been recorded for Upper and Lower Cretaceous beds as well as later horizons. The specimens are poorly preserved and specific identification cannot be established at present.

Figured specimens: U.S.N.M. 108176a, 108176b.

Sagia Yen, new genus

Shell sinistral, ovately globose to ovately oblong in outline, having an elevated spire and more or less dilated body whorl. Whorls more or less convex and moderately shouldered, increasing rapidly in size, and having fine sculpture. Aperture descending in front, more or less ovate in outline, having apparently simple peristomal margin, but outer lip slightly thickened externally.

Genotype: *Sagia physoides* Yen.

The genus is characterized by its sinistral coiling, elevated spire, descending body whorl, gently convex and moderately shouldered whorls. It resembles *Bythinella* Moquin-Tandon of Europe, but it differs from that genus by its sinistral coiling of shell, more distinctly shouldered whorls and slightly thickened outer lip.

Sagia physoides Yen, n. sp.

Plate 1, fig. 10

Shell sinistral, ovately oblong in outline, having a highly elevated spire and moderately inflated body whorl. The spire is slightly greater than the body whorl. Whorls rapidly increasing in size, gently convex and bearing faint lines of spirals, which are more distinctly shown on the body whorl. Suture well impressed, aperture not observable, probably ovate in outline having simple peristomal margin, but slightly thickened externally on the outer lip.

Altitude of shell	8.0
Width of shell	5.0
Height of aperture	–
Width of aperture	–
Number of whorls	6

Holotype: U.S.N.M. 108178; paratypes: U.S.N.M. 108177a–f.

Sagia elongata Yen, n. sp.
Plate 1, fig. 11

Shell sinistral, elongately ovate in outline, having a spire nearly as high as the body whorl. Whorls rapidly increasing in size, gently convex and slightly shouldered. The body whorl is descending and more or less reduced at the base. Aperture probably somewhat oblong in outline, having outer lip thickened externally.

Altitude of shell	5.4
Width of shell	2.8
Height of aperture	–
Width of aperture	–
Number of whorls	5

Holotype: U.S.N.M. 108180; paratypes: U.S.N.M. 108179.

Sagia amnicoloides Yen, n. sp.
Plate 1, fig. 12

Shell sinistral, narrowly ovate in outline, having a spire nearly as high as the body whorl. Whorls rapidly increasing in size, roundly convex, well shouldered and separated by deeply impressed suture. Aperture descending, ovate in outline, having outer lip thickened externally.

Altitude of shell	3.8
Width of shell	2.0
Height of aperture	2.0
Width of aperture	–
Number of whorls	6

Holotype: U.S.N.M. 108181a; paratypes: U.S.N.M. 108181b.

Sagia globosa Yen, n. sp.
Plate 1, figs. 13-14

Shell sinistral, ovately globose in outline, having a spire

nearly as high as the body whorl. Whorls gradually increasing in size, roundly convex, well shouldered, and bearing distinct spiral lines and faint lines of growth. Suture deeply impressed. Body whorl moderately dilated and slightly reduced at the base. Aperture broadly ovate in outline as determined by the convexity of the body whorl.

Altitude of shell	2.8
Width of shell	2.0
Height of aperture	–
Width of aperture	–
Number of whorls	5

Holotype: U.S.N.M. 108182; paratypes: U.S.N.M. 108183.

Family Ellobiidae

Zaptychius cf. *Z. haldemani* (White)

Plate 1, fig. 19

Tortacella haldemani White, U. S. Geol. Survey Bull. 128, p. 44, plate 5, figs. 8-12, 1895.

Zaptychius haldemani is characterized by its small size, cylindrically slender outline of shell, fine and close riblines of sculpture and two columellar plicae. The single specimen in the present collection resembles this species but differs by its smaller size, more dilated body whorl and absence of distinct sculpture.

Figured specimen: U.S.N.M. 108185b.

Zaptychius sp. undet.

Plate 1, figs. 15-18, 20

This form differs from the preceding one by its much larger size, more strongly developed sculpture and more prominently shouldered whorls. Numerous imperfectly preserved specimens were found in the collection and it seems to be a rather common form in the present bed.

Figured specimens: U.S.N.M. 108189, 108190, 108191, 108193, 108194.

Family Physidae

Physa cf. *P. usitata* White

Plate 1, figs. 25-28

Physa usitata White, U. S. Geol. Survey Bull. 128, p. 47, plate 6, figs. 8-9, 1895.

A number of specimens in the present collection resemble this species by having a short and acute spire, but are readily separated by their larger size, more gibbous body whorl and thin columellar margin. The species was originally described from the Bear River beds.

Figured specimens: U.S.N.M. 108195, 108196a.

Physa cf. *P. kanabensis* White
Plate 1, figs. 31-33

Physa kanabensis White, in Powell's Report Geol. Uinta Mts., p. 119, 1876.

A number of specimens here in narrowly oblong outline resemble *P. kanabensis* White, which was described from Southern Utah (not *P. kanabensis* recorded and figured by the same author in 1886 from Wales, Utah). The present form has a much shorter spire and less descending body whorl.

Figured specimens: U.S.N.M. 108198, 108199, 108197.

Family Planorbidae
Anisopsis cf. *A. minuta* Yen
Plate 1, figs. 34-39

Anisopsis minuta Yen, U. S. Geol. Survey Prof. Paper 233-A, part 2, p. 16, plate 2, figs. 13a-c, 1951.

Numerous individuals in the present collection resemble closely *A. minuta* Yen in size and outline of shell, but differ by having more closely coiled whorls, with obtusely angulated shoulder and more concave base.

Figured specimens: U.S.N.M. 108201-108206.

Family Helminthoglyptidae
Mesoglypterpes Yen, new genus

Shell helicoid in outline, perforate or narrowly umbilicate, having a more or less elevated spire and somewhat compressed body whorl. Whorl gently convex, gradually increasing in size, closely coiling above the periphery and bearing decussate spiral and riblines. Suture well impressed. Aperture probably subovate in outline, outer lip thin and slightly reflected.

Genotype: *Mesoglypterpes sagensis* Yen.

The genus is characterized by its small size, closely coiled whorls, perforate umbilicus, decussate sculpture and reflecting

outer lip margin. It is much smaller in size, having a more depressed spire and a more compressed body whorl than *Glypterpes* Pilsbry, a genus described for some early Tertiary species of terrestrial gastropods.

Mesoglypterpes sagensis Yen, n. sp.
Plate 1, figs. 40-43

Shell helicoid in outline, small in size (less than 10 mm. in diameter), perforately umbilicate, having a depressed spire and compressed body whorl. Whorls scarcely convex and gradually increasing in size. The sculpture consists of distinct and close spiral lines and equally well developed riblines. Suture well impressed. Aperture probably subovate in outline, having its outer lip thin and well reflected.

Altitude of shell	–
Width of shell	6.5
Height of aperture	–
Width of aperture	–
Number of whorls	5½

A number of specimens was found in this bed and its occurrence seems to be quite common. None of them is well enough preserved to show a perfect view of the aperture, but some of them have the outer lip margin exposed and others show the perforate umbilicus.

Holotype: U.S.N.M. 108186; Figured paratypes: U.S.N.M. 108187a-c; Unfigured paratypes: U.S.N.M. 108188a-m.

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AVERAGE CHEMICAL COMPOSITION OF THE SEDIMENTARY ROCKS

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ABSTRACT. A careful comparison of the average chemical composition of all igneous rocks with that of all sedimentary rocks reveals a greater discrepancy than may be accounted for on grounds of insufficient data. The amount of calcium especially is much greater than anticipated, which leads me to assume that the parent material for the sedimentary rocks was not always like recent igneous rocks. I propose as a possible explanation that the primary sial crust of the Earth had a composition different from that of the crust at the present time.

THE problem of the average composition of the sedimentary rocks is rather puzzling.

One point is very clearly presented by Pettijohn (1949, p. 3), namely the discrepancy between the expected average composition of the sedimentary rocks and that obtained as an average from all known data. The expected average composition is based on the assumption that this average must correspond to the average composition of the igneous rocks, the only known parent material for sedimentary deposits. Ninety-nine per cent of all sedimentary rocks may be considered as consisting of shales, sandstones and limestones, or of mixed rocks which may be divided proportionally among the three.

Clarke (1924, p. 34) estimates the theoretically expected proportion of shale:sandstone:limestone as 16:3:1. The newest calculation of the actual proportion in all known existing rocks (Pettijohn, 1949, p. 5) gives a very different ratio—2.9:1.1:1. In other words there is in the known part of the Earth's crust more than five times less shale than expected, and nearly three times less sandstone, if limestone is used as a unit of comparison. (There are other calculations of this fundamental proportion, for example those of Holmes (1937, p. 75) slightly different from that presented here, but they do not change the main issue. The amount of limestones is too great in proportion to other types.)

I have tried to calculate the average composition of all known sedimentary rocks, taking as a basis for calculation the Pettijohn ratio for the three principal types of sedimentary rocks, viz. 2.9:1.1:1, and adding my estimate for salt (0.3%),

gypsum (0.2%), iron ore (0.2%), phosphates (0.1%). This calculation, on a water free basis, gives:

SiO_2	52.65 %
TiO_2	0.53
Al_2O_3	9.64
Cr_2O_3	0.04
Fe_2O_3	2.86
FeO	1.54
NiO	0.002
MnO	0.056
MgO	1.56
CaO	13.93
BaO	0.05
SrO	0.03
K_2O	2.55
Na_2O	1.56
P_2O_5	0.18
S	0.40
C	0.54
CO_2	11.44
Cl	0.38
Others	0.062
	100.00

In order to make a comparison with the igneous rocks easier, I have recalculated the results on the basis of an absence of elements derived from the air: CO_2, C, SO_3, but as a part of material is retained permanently in solution in the sea water I have included in the calculated average the estimated amount of each salt present in sea water. The result (table 1, column 2) compared with the average composition of the igneous rocks recalculated on a water free basis (column 1) is as follows:

TABLE 1

Components	Average of igneous rocks	Average of known sedimentary rocks	Difference
SiO_2	59.80 %	59.46 %	—0.34
TiO_2	1.06	0.60	—0.46
Al_2O_3	15.50	10.90	—4.60
Cr_2O_3	0.053	0.04	—0.015
Fe_2O_3	3.11	3.10	—0.01
FeO	3.84	1.74	—2.10
NiO	0.025	0.002	—0.023
MnO	0.28	0.06	—0.22
MgO	3.52	1.96	—1.54
CaO	5.14	15.60	10.46
BaO	0.06	0.06	—
SrO	0.022	0.03	0.008
K_2O	3.16	3.07	—0.09
Na_2O	3.88	2.27	—1.61
P_2O_5	0.30	0.20	—0.10
Cl	0.04	0.45	0.41
Others	0.21	0.358	
	100.00	100.00	

The differences in composition of the igneous and sedimentary rocks (column 3) seem much in excess of probable errors in analysis or in estimation of the part played by different rock types.

The presented average of all sedimentary rocks (column 2) corresponds, however, to all rocks deposited on the continental area only (including the shelf); in other words the material carried into the open ocean in chemical solution, in suspension, and by organisms is not represented in that average.

How much may the deep-sea sediments influence the average composition of sedimentary rocks? What probable proportion do the whole of the deep ocean deposits bear in relation to all other deposits for the whole Earth's history?

Let us suppose for argument's sake that the average area covered by ocean—I mean true ocean, beyond the slopes of the continents—has been throughout geological time not much different from what it is at present. This is probably not the exact truth, but is suitable for a first approximation.

We may assume further that the slowly accumulating deep-sea red clay is the most characteristic sediment of the deep sea, and that its rate of deposition was not much different from the present rate of about 8 mm. per thousand years. This amount, I estimate, may be reduced to about 3 mm. during the long process of diagenesis. On the assumption that the red clay corresponds approximately to the average deep-sea deposit, we may reason as follows. It is true that today the red clay covers only about half of the ocean bottom. One-third of it is covered by calcareous deposits, chiefly of the character of *Globigerina* ooze, of which carbonate of lime forms two-thirds. (The figure often given that one-half of the bottom is covered by *Globigerina* ooze includes that part of the deposits on the slopes of continents.) The remaining one-third is clayey matter very near though not identical in composition to the red clay. The calcareous deposits should influence the average in an important way. But calcareous plankton has existed only from the beginning of the Mesozoic age, which is no more than, say, 180 million years (Holmes, 1937) or only during 1/20 part of the presumed length of geological time. Thus carbonate of lime forms no more than $\frac{2}{3} \times \frac{1}{3} \times 1/20 = 1/90$ part of the total mass of the deep-sea deposits, and influences the average only slightly. If the role played by calcareous

deposits has been greater than this, the excess of calcium in the calculated average will be still greater.

But Rankama (1950) supposes that, before Cambrian times, lack of organisms with calcareous shells permitted the carbonate of lime dissolved in river water to reach the ocean without being precipitated in the shallow seas. If valid, this admittedly increases the amount of calcium in Precambrian deep-sea deposits, but as it reduces by the same amount calcium present in Precambrian shallow sea deposits, the final average for calcium is not affected.

The influence of siliceous oozes like radiolarian and diatom oozes upon the average composition of deep-sea deposits is still smaller than that of the *Globigerina* ooze. Diatom ooze is practically unknown before the Tertiary period; radiolarian ooze has probably been deposited from Precambrian times, but it differs from red clay very slightly in chemical composition being slightly richer in silica.

The blue mud which fills the deepest known troughs on the ocean bottom (I don't count that part of the blue mud on the continental slope) does not differ markedly in chemical composition (only silica is about 12% higher) from the red clay, but it is accumulating much more quickly, on rather a small part of the bottom. As the red clay is the type of sediment with the slowest rate of deposition, all these corrections increase the total amount of deep-sea deposits, rather than change the average composition (the average amount of silica must be slightly affected).

But limiting ourselves to the red clay only, we still get the rather unexpected conclusion that from the beginning of the Cambrian period, estimated as at least 500 million years ago, 1500 meters of shale derived from the red clay should have accumulated.

Is it possible to carry this reasoning farther back into Precambrian times? I should think so. Even if the total amount of water on the surface of the Earth might have increased through the ages, as some authors think, such increase would have proceeded very slowly. Kuenen (1950, p. 129) has estimated that the yearly increase of water resulting from volcanic activity is no more than 1/10 of a cubic kilometer per year. Even if his estimate is doubled it follows that, at the present high rate of volcanic activity, the amount of water on the

whole globe has increased from the beginning of Cambrian time no more than 7.4 per cent (44 per cent for the 3000 million years of the Earth's history). In other words there is a strong probability that at the end of Precambrian time the amount of water, though less than now, was of the same order of magnitude as it is today. If so, then we are presented with two possibilities: either sial was uniformly distributed over the globe so that one not very deep ocean covered the whole surface of the Earth and there was no erosion and practically no sedimentation; or continents did exist, with of necessity one ocean basin or more where the water could find a place.

There exist plenty of proofs from every continent of big scale destruction of rocks by erosion in Precambrian times. The sandstones of detrital origin (e.g., Torridon sandstone, Jotnian sandstone) or their metamorphic products are known not only from Algonkian but from Archaean times, even from early Archaean. The great mass of such rocks indicates that mere small islands alone were insufficient to account for the necessary material. There must have been continents to supply the enormous mass of grains of detrital origin. But if so it is only logical to assume the existence of oceanic basins, with oceanic depths as old as the oldest known rocks.

But the oldest rocks are supposed to be about six times older than the beginning of Cambrian times; thus we may expect about 9000 meters or 9 kilometers, i.e., a layer nearly 6 miles thick, of rocks of deep-sea character gathered and mostly hidden under the ocean bottom, probably highly altered.

Even if we count all continental slope deposits with the continental deposits, deep-sea deposits cover today over three-fifths of the surface of the globe. Thus the total amount of deep-sea sediments exceeds 2.7×10^{12} cubic meters. The remaining two-fifths is occupied by continental seas, continents and shelves and slopes of the continents. The amount of sedimentary rocks existing or deposited on that continental area is still more difficult to estimate. Many attempts have been made by various authors with very divergent results. The sediments accumulate only on part of this area both above and below sea level, partially in inner continental basins, partially in inner seas, partially on the shelves, partially on the oceanic slopes.

The remaining part of the continents is undergoing destruc-

tion (erosion) and material is removed, not deposited. Any particular region has changed its character often, being at one time eroded, then covered with sediments, again eroded, and so on. But the total area under erosion, in relation to the total area under accumulation of sediments, has probably oscillated during the geological history about the present ratio which, roughly speaking, may be taken as 1:1; i.e., about one-fifth of the earth surface is undergoing destruction and supplying material for all sedimentary rocks.

The sediments accumulating on the continental areas are much more heterogeneous than those in the ocean's depth. They are growing at very different rates, in one place perhaps 1000 times quicker than in a neighboring one, on the average no less than twelve times quicker than in the deep seas. Another complication is that sediment once formed is not permanently preserved under the sea bottom, but as often as not is exposed to a new cycle of erosion, and perhaps later to still another one. How many times some material passes through the process of erosional destruction is guess. A large part of the sediments has undergone not only diagenetic but metamorphic changes also, often so far that even the recognition of sedimentary origin is not always easy or possible. The estimate of 40 mm. per thousand years for the accumulation of deposits on the continental area is a very rough approximation, but it agrees fairly well with the existing estimate for average lowering of the land surface as a result of erosion. According to expressed opinions, some river basins are being lowered about 5-10 mm. per hundred years for not very flat country; the erosion ratio is much smaller in complete plains, but enormously greater in mountains. An average of about 60 mm. per thousand years is probable, and the difference with the figure for continental accumulation may be accounted for by the amount of material removed to the oceans. In this estimate of land lowering I have included Clarke's estimate of 1 cm. in 1000 years for the amount of material taken to the sea in solution (1924, p. 121).

If we assume that the accumulation rate on the continental area is not far from 40 mm. per 1000 years on half of the area, and nothing on the other half, which is undergoing destruction, we get 20 mm. as an average for the whole continental area, which is over six times quicker than on the deep sea bottom.

In other words, if the same material had not been reworked many times, more than 60 km. thickness of crust would have accumulated by sedimentation alone during the geological history of the earth, and about 90 km. destroyed by erosion—much more than the total thickness of the sial.

As only about one-quarter of the continent surface is composed of igneous rocks, I assume, as a guess, that average reworking of the same material reduced this amount about four times, and I consider a layer of rocks over 20 km. thick as the probable amount of material destroyed by cumulative destruction by erosion.

As this amount is in no way certain, I have tried to calculate it on a completely different basis. Chlorine is present in the igneous rocks in an amount of 0.48 kg. per ton. According to Clarke (1924, p. 138) the amount of chlorine in the sea water is $25{,}538 \times 10^{12}$ tons. Not all this chlorine came from destruction of igneous rocks, part being derived directly from volcanoes. But some volcanic chlorine may not be delivered for the first time into sea water; sea water impregnates and is included in deeply buried sediments through which a magma is penetrating on its way to the sea bottom. On the other hand some chlorine is present in the salt incorporated into deep-sea sediments (average of 6 per cent of water with 1.9 per cent of Cl in a 9,000 m. thick series), and in the salt removed to the continental area in evaporites, which is more difficult to estimate—existing estimates seem too low, especially in view of newly discovered salt deposits; I think it may even form a quarter to a third of the total sea salt, if we consider the probable Precambrian salt also. I think these two values —the amount of chlorine outside that in sea water and the amount derived from volcanoes—balance one another or nearly so; hence I consider below that the whole of recent sea chlorine originated from the destruction of the continental rocks.

To obtain that amount of chlorine it is necessary to destroy $\sqrt{\frac{25.538 \times 10^{12}}{0.48 \times 10^{-3}}}$ metric tons = approx. 50×10^{18} metric tons of rocks, or taking 2.80 as the average specific gravity of igneous rocks, 17.9×10^{18} cubic meters of rocks.

Erosion being limited practically to two-fifths of the globe's surface—that is, about 200 million square km.—the average thickness of igneous rocks destroyed, in order to get the present

concentration of salt in the sea, corresponds roughly to a layer 90 km. thick over the continental area. This result does not take into account the amount of destroyed sedimentary rocks, which yield practically no chlorine, or only return the chlorine taken from the sea.

In discussing the chlorine method I have been thoroughly aware of the difficulty connected with all estimates of the products of accumulation in the seas of material brought in solution from the continents, and using it for time reckoning. Long ago Sollas, then Clarke and others, tried to estimate the age of the ocean by the sodium method, calculating how long it would take to bring the sodium in the sea to its present concentration. They got a figure near 100 million years and all corrections of Kuenen or others do not change the fact that at the existing rate of accumulation the present concentration of salt would have been reached in Archaean times. Chlorine brought by existing rivers would have come up to present concentration in a little over 200 million years. For the moment we do not know how to attack this problem.

For this reason I am not going to use the number obtained by the chlorine method, but it serves to indicate in a completely different way how big are the masses of rocks that have been destroyed. The value obtained is much greater but comparable to that obtained by the first method, presuming that no chlorine was present in the sea water in the primary ocean (only an assumption).

Returning to the former method, which indicated that a layer of rocks 20 km. thick has been destroyed on the continental area, I get as a best first approximation that the total amount of continental deposits is 3.2×10^{12} cubic meters.

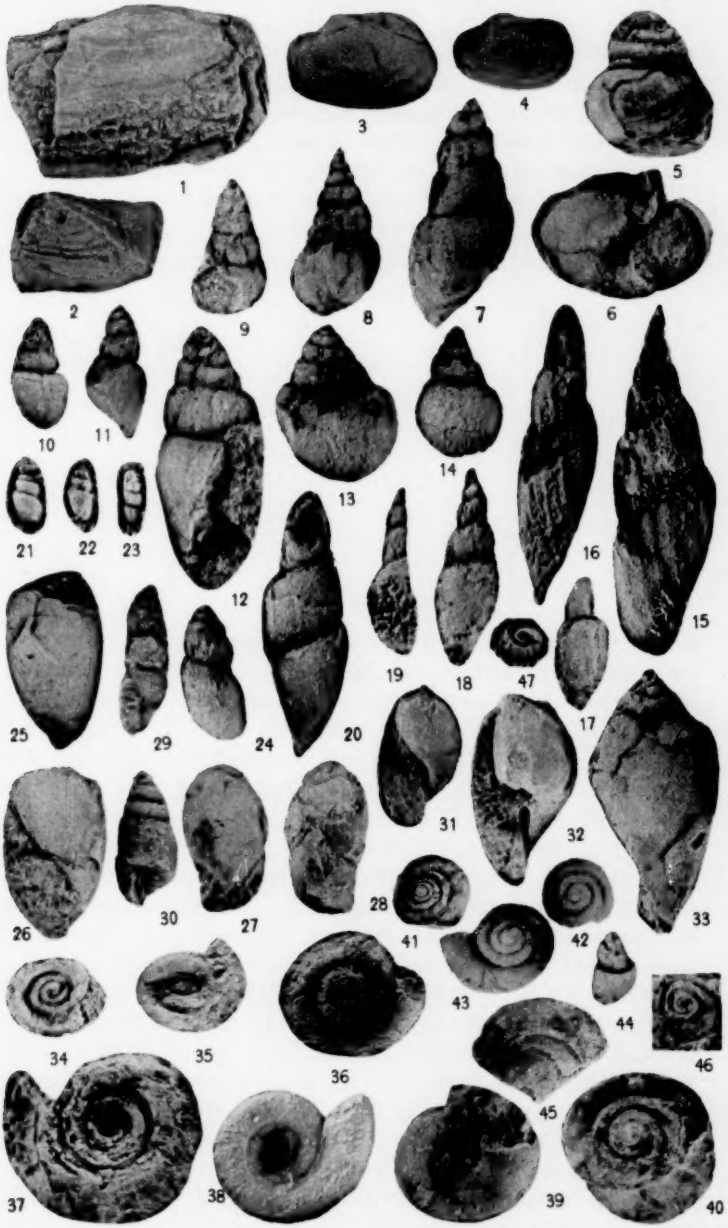
The deep-sea deposits should amount to 2.7×10^{12} meters for a pure red clay, as I have stated above. This amount should be reduced for submarine volcanic material to 2.35×10^{12} cubic meters. But as some sediments in the deep sea are growing much more quickly, I think it is necessary to increase the total value by about 0.5×10^{12}, which gives 2.85×10^{12} cubic meters.

Both amounts being of the same order of magnitude, the results may be taken as 1:1, remembering that the calculation is a very rough approximation at best. For this reason I consider below that the ratio of deep-sea sediments (including

the old sediments probably highly metamorphosed today) to all other sediments (and also their metamorphic products) is near to 1:1. On this basis I have tried to calculate the probable composition of all sedimentary rocks, assuming that the average of both groups of sediments should match the average composition of igneous rocks. The average composition of the sediments of the continental area (with shallow seas, etc., of course) has been presented above; the expected composition of deep-sea sediments is presented here, assuming that the average of both in proportion one to one should correspond to the igneous average. The calculation was made on a water free basis, free from the elements from the air such as C, CO_2, SO_3:

SiO_2	60.18	%
TiO_2	1.52	
Al_2O_3	20.10	
Fe_2O_3	3.06	
FeO	5.94	
MnO	0.50	
MgO	5.08	
CaO (minus value —5.32)		
K_2O	3.25	
Na_2O	5.47	
P_2O_5	0.40	
Cl (minus value —0.41)		

Of course, the result obtained is not real, because for calcium and chlorine minus values were obtained, but this perhaps underlines still better the existing excess of calcium in the sedimentary rocks from the continental area. It indicates that even a complete lack of Ca in the deep sea part of sediments does not balance it, and the actual deep deposits are far from being free from calcium. To compare the theoretical results with an average of existing deep-sea deposits, we must remember that part of the material of the deep-sea deposits is derived from deep-sea submarine volcanic activity. It is very difficult to decide which part of fine clay is from one or other origin and opinions of authorities are divided (Clarke, 1924; Murray and Renard, 1891; Sverdrup, 1942). Very elaborate researches of Harrison and Jukes-Browne (1895) brought them to estimate volcanic glass at 23% for one particular station of the Challenger Expedition. The volcanic oceanic material plays today a much more important role in the Pacific than in other oceans; on the other hand we are living in a period of rather intensive volcanic activity, probably above the average for the whole geological history. Having this in mind, I have taken the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probable proportion of oceanic volcanic material to other deep-sea sediments as 1:7, but even admitting a much higher proportion, we are not going to change the results much. The average composition of oceanic volcanic material I have tried to calculate on a water free basis from 15 of the most characteristic analyses published by Clarke (1924, pp. 460-472):

SiO_2	47.54 %
TiO_2	1.35
Al_2O_3	13.73
Fe_2O_3	3.32
FeO	6.57
MnO	0.13
MgO	9.97
CaO	10.07
BaO	0.07
SrO	0.04
K_2O	2.52
Na_2O	3.09
NiO	0.02
P_2O_5	0.57
V_2O_5	0.015
As_2O_5	0.02
S	0.01
Cl	0.03
F	0.02

I have calculated the average for deep-sea sediments in the following way. I took the average for the red clay, subtracted 1/8 for volcanic material of the composition given above, then corrected for 1.1 per cent pure calcareous material and for 0.5 per cent of siliceous oozes. (This, of course, does not correspond to the average present-day composition of oceanic sediments which is presented below.) To obtain the representative average for red clay I used Steiger's data for analysis from material from 51 red clay stations (Clarke, 1924, p. 518); then I recalculated all Challenger data for typical red clay (I used 25 samples of the red clay poor in CO_2) recalculated on water free basis, CO_2 and SO_3 free, and used the average. The results (SiO_2—59.00%, Al_2O_3—16.80%, Fe_2O_3—16.61%, FeO—1.25%, MnO—1.88%, MgO—1.65%, CaO—4.80% K_2O—1.65%, Na_2O—1.32%, P_2O_5—0.19%) were rather far from Steiger's data. This is partially the result of the method of computation; Steiger deducted all carbonate of lime while I consider that calcium should be included, as material not derived from air. This doubles the amount of lime and slightly diminishes the other results. Still the discrepancies are large, chiefly in iron and magnesium. Differences in alkali are par-

tially removed when we remember that the sea salt present in samples was not included in the Challenger analyses. A great drawback of the Challenger data is the lack of a determination of titanium in the normal analyses.

After having accounted for this difference, I have calculated the average between the Challenger Report and Steiger data (both sets of analyses executed on the material from the same expedition); then I have introduced correction for other published data for the Pacific and Atlantic in proportion to the number of samples analyzed (Sverdrup, 1942, p. 992; Correns, 1935, pp. 247, 232, 305; Philippi, 1912). This average for red clay was corrected for calcareous and siliceous deposits. The result is presented in the lefthand column below; the column on the right is corrected for volcanic material according to the view presented above. The second column represents then the average probable composition of material deposited in the deep ocean and originating from the continental part of the globe:

SiO_2	57.43 %	58.81 %
TiO_2	0.98	0.94
Al_2O_3	17.50	18.04
Cr_2O_3	0.013	0.013
Fe_2O_3	8.70	9.47
FeO	1.03	0.23
NiO	0.04	0.04
MnO	1.23	1.53
MgO	2.76	1.73
CaO	4.91	4.26
BaO	0.18	0.19
SrO	0.06	0.06
K_2O	2.48	2.46
Na_2O	1.48	1.25
V_2O_5	0.04	0.04
CuO	0.06	
PbO	0.008	
ZrO	0.15	
As_2O_5	0.001	
ZnO	0.001	
P_2O_5	0.28	0.24
Others	0.667	
	100.00	

This second column should correspond to the expected theoretical composition of the deep-sea deposits.

We know that agreement can't exist because we get a minus value for calcium. Agreement for the three main components—silica, aluminum, and iron (considering both forms of iron compounds together)—is reasonably good, but agreement in

the others is rather poor; the deep-sea deposits are much too rich in calcium, barium, and manganese, and too short of magnesium, potassium, phosphorous, and markedly of sodium.

The total average for all known sedimentary rocks, both from the oceanic and the continental part of the Earth, comes out as follows:

Components	My calculation	Kuenen	Difference with igneous average: After myself	Difference with igneous average: After Kuenen
SiO_2	59.17 %	58.16 %	—0.63	—1.64
TiO_2	0.77	0.94	—0.29	—0.12
Al_2O_3	14.47	15.93	—1.03	—0.38
Cr_2O_3	0.03		—0.025	
Fe_2O_3	6.32	8.54	+3.21	+2.20
FeO	0.99		—2.85	
NiO	0.02		—0.005	
MnO	0.80	0.64	+0.52	+0.35
MgO	1.85	3.58	—1.67	+0.06
CaO	9.90	6.26	+4.74	+1.12
BaO	0.12		+0.06	
SrO	0.04		+0.02	
K_2O	2.77	2.85	—0.39	—0.31
Na_2O	1.76	1.85	—2.12	—2.03
P_2O_5	0.22	0.26	—0.08	—0.04

The first column represents my results, the second the newly published calculation in Kuenen's book (1950, p. 389), the third and fourth the difference between the average sedimentary and average igneous rocks according to my results and those of Kuenen, respectively. In Kuenen's results the whole of iron is presented as Fe_2O_3. In my calculation, after ferrous iron is converted to ferric, the net difference is only of 0.07% between the igneous and sedimentary average, which is the best agreement among all the important components.

Kuenen's and my results for the alkalies are very near to one another, especially in view of my quite different method of calculation, and both show a difference from the igneous average, especially great for sodium.

The smaller excess of calcium in Kuenen's calculation is probably explained by his using Steiger's data alone for the composition of red clay; these data were calculated on a $CaCO_3$ free basis.

This lack of agreement between the average of all sedimentary and all igneous rocks leads to the supposition that the primary composition of the Earth's crust was different from its present day composition, as otherwise it is difficult to find a possible source of the material; a meteoritic source seems too

small, and the amount of calcium derived from decomposition of radioactive potassium seems too small also. If so then the primary continental rocks should have been poorer in alkali, especially in sodium, poorer in magnesium, richer in calcium, to mention the main constituents. This means they were farther from a granitic and nearer to a dioritic or even gabbroic composition than igneous rocks are today.

It seems quite possible that perpetual reworking by erosion of the continental blocks brings fresh material from underneath (as a result of volcanic activity, or simply by exposure of deeper strata) that is not identical with the primary crust in chemical composition. This of course borders very near to the problem of granitization.

In my estimation of the average deep-sea deposits I had in mind the average composition for the Earth's history, which does not correspond to the present average. To show the difference I present my calculation of today's average composition of deep ocean deposits based on all analyses which included calcium carbonate. I consider here only sediments accumulating in the true ocean beyond the shelf and the continental slope in an average in depth of over 2500 meters.

To get the right proportion of each type of deposits I multiplied the surface occupied by each type by a probable factor for rate of deposition, taking the red clay rate as 1. I got the following results for the principal types of deposits. Such varieties as pteropod ooze and coccolith ooze are included in the *Globigerina* ooze:

	sq. miles										
Red clay	51,500,000	42.3%	of	deep	ocean	rate	1	, volume	of	dep.	20.6%
Globigerina ooze	49,920,000	41.5%	"	"	"	"	3	"	"	"	60.4%
Diatom ooze	10,880,000	8.9%	"	"	"	"	2.5	"	"	"	10.8%
Radiolarian ooze	2,290,000	1.8%	"	"	"	"	1.3	"	"	"	1.6%
Blue mud	7,250,000	5.8%	"	"	"	"	2.5	"	"	"	7.0%
Volcanic mud	600,000	0.5%	"	"	"	"	2.0	"	"	"	0.4%

Blue mud includes the terrigenous deposits around Antarctica, but does not include the deposits on the continental slopes.

Average composition of each type of deep-sea deposit (water, C, CO_2, SO_3 free):

Component	*Globigerina* ooze 66 stations	Volcanic mud 5 sta.	Red clay 45 sta.	Radiolarian ooze 7 sta.	Blue mud 18 sta.	Diatom ooze Antarctic 4 sta.	Diatom ooze N. Pacific 2 sta.
SiO_2	12.65%	42.16%	54.99%	64.47%	65.29%	82.36%	67.18%
TiO_2	0.21	0.76	0.81	0.60	0.82	0.30	0.60
Al_2O_3	6.39	12.10	17.35	13.76	16.61	4.87	14.35
Fe_2O_3	6.30	10.26	13.41	9.63	8.56	2.23	6.72
MnO	0.83	0.10	1.29	1.24	0.30	0.10	0.96
MgO	1.29	2.81	2.14	3.37	2.26	1.84	2.73
CaO	68.68	31.46	6.24	3.19	2.76	7.85	2.19
K_2O	1.20	1.53	2.07	1.71	1.76	traces	2.42
Na_2O	2.03	1.33	1.40	1.01	2.57	traces	2.13
P_2O_5	0.40	0.13	0.17	0.31	0.22	0.09	0.15
ZrO_2	0.13	0.14	0.16	0.08	0.17	0.01	0.01
CuO			0.01	0.05			
Cl	0.47		0.49	0.75	0.40		0.56

North Pacific diatom ooze forms about 1/20 of all surface covered by diatom oozes. It is too different from the Antarctic type to consider them together, as the former is nearer to red clay in composition.

The overall average of deep-sea sediments is then as follows:

SiO_2	33.75%
TiO_2	0.44
Al_2O_3	8.75
Fe_2O_3	7.90
MnO	0.81
MgO	1.56
CaO	43.08
K_2O	1.35
Na_2O	1.64
P_2O_5	0.30
ZrO_2	0.11
Cl	0.36
	100.05%

My estimate of the amount of sedimentation is at variance with many authoritative opinions. To discuss this fully would result in a long essay far beyond the scope of the present paper, but I may stress that even a much smaller rate of sedimentation and erosion during the Earth's history than I postulate does not change the main issue. The discrepancy remains practically the same even if one takes for example Clarke's data for the amount of the sedimentary rocks.

I am glad to express my very best thanks to Dr. W. Campbell Smith, Keeper of Mineralogy in the British Museum (Natural History), for the interest he has shown in my work,

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FORM OF DIABASE SHEETS IN SOUTHEASTERN PENNSYLVANIA*

PRESTON E. HOTZ

ABSTRACT. Ringlike outcrop patterns are characteristic of diabase intrusions of Triassic age in southeastern Pennsylvania. Drill-hole and geophysical data indicate that the diabase of these rings has the form of generally discordant curved sheets. Pre-existing fractures or potential lines of weakness may have controlled the sheetlike form, or pressure may have forced the diabase magma to spread laterally rather than to rise vertically.

INTRODUCTION

OVAL and elliptical outcrop patterns are characteristic of diabase bodies in the Triassic belt of southeastern Pennsylvania. The Geologic map of Pennsylvania (Stose and Ljungstedt, 1931) from which figure 1 was taken shows a belt of several elliptical rings of diabase in the northwestern part of the Triassic basin beginning south of Reading and extending northeast to the Delaware River. Another series of smaller and less well-defined rings of diabase extends southwest from Cornwall to Dillsburg. A single small almost circular ring of diabase is found just north of the Pennsylvania-Maryland boundary southwest of Gettysburg.

Most of the intrusions in the Triassic belt have heretofore been interpreted as conventional sills and steeply dipping, dikelike discordant bodies with concordant sill-like and basin-like offshoots (Stose and Lewis, 1916, p. 628; Stose and Bascom, 1929, pp. 11-12; Stose and Jonas, 1933, p. 42; Stose and Jonas, 1939, pp. 125-126; Stose, G. W., 1949, pp. 533-535). In 1908 Spencer (1908, pp. 44-45) suggested that the chain of ringlike diabase intrusions in the northeastern part of the belt was the surface expression of a "practically unbroken sheet." Drill-hole explorations at Dillsburg (Hotz, 1950, pp. 11-13) and elsewhere, and a gravity survey near Quakertown (Hersey, 1944, p. 439) have confirmed Spencer's interpretation and justify the conclusion that a sheetlike habit is characteristic of most of the diabase masses that have oval or ringlike outcrop patterns.

* Publication authorized by the Director, U. S. Geological Survey.

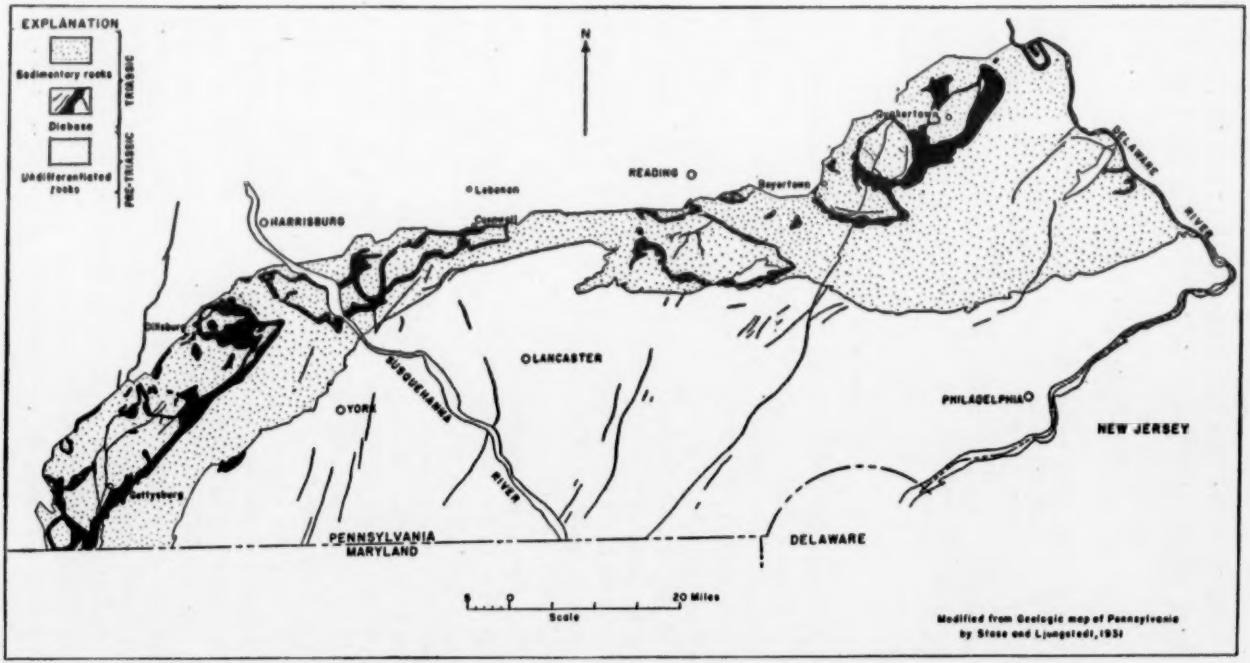

Fig. 1. Map of southeastern Pennsylvania showing distribution of Triassic diabase intrusions.

STRUCTURAL HISTORY OF THE TRIASSIC BASIN

The Triassic belt of southeastern Pennsylvania represents a continental basin in which terrestrial sediments were deposited. During deposition of the sedimentary rocks the basin gradually sank, owing to downward flexing or faulting along its northwest edge (Stose and Jonas, 1939, pp. 107-108, 119). The northwest border is marked by a fault boundary in many places, whereas the southeast limit is nearly everywhere an unconformable depositional contact on older rocks. Fracturing of the basin provided vents for the upward movement of magma, which intruded the sedimentary rocks and solidified as diabase. The sedimentary rocks were metamorphosed to quartzite and hornfels near the diabase intrusions. Diastrophic activity virtually ceased in this Triassic basin before or at the time of diabase intrusion.

The Dillsburg District.—At Dillsburg an area of Triassic sedimentary rocks about 6 miles long and 3 miles wide is nearly surrounded by diabase (fig. 2). The diabase is an offshoot from the large westward-dipping sill that extends northeast from Gettysburg, Pennsylvania. A small oval patch of diabase that is separate from the surrounding body lies near the western end of the central area of sedimentary rocks. Beneath this small body of diabase are small replacement bodies of magnetite in lenses of limestone conglomerate within the sedimentary rocks (Hotz, 1950, pp. 13-25).

The average strike of the sedimentary rocks is east-northeast and the average dip is about 30° NW. In places the rocks are gently flexed, but the regional structure is generally homoclinal and has a gentle northwest dip.

Over much of its extent the diabase surrounding the central area at Dillsburg is discordant with the structure of the sedimentary rocks, though part of the southern and southeastern contact appears to be concordant.

Spencer (1908, pp. 71-72) interpreted the oval body of diabase overlying the magnetite deposits at Dillsburg as in part discordant, though in his description of the mines he assumed concordant relations in most places. Harder (1910, p. 601) interpreted this same body of diabase as a sheet that ". . . apparently lies on the sediments with a rolling uneven contact, while the outlying smaller masses appear to be erosion remnants lying in troughs on the surface of the sedi-

ments. The sediments underneath the diabase are continuous with those surrounding them and have the same prevailing dip . . ."

Diamond drilling (Hotz, 1950, pp. 11-13) has proved Harder's concept of the structure to be correct. In each drill hole a cap of diabase 60 to 100 feet or more thick was penetrated above the metamorphosed sedimentary rocks. From

Fig. 2. Geologic map and section of northwestern York County, Pennsylvania.

the structure section exposed by the drill holes (fig. 3) it is evident that the contact of the diabase with the underlying sedimentary rocks is discordant and essentially flat.

Several drill holes encountered a second body of diabase below the sedimentary rocks. This lower intrusive body was not known prior to the drill-hole exploration. Its upper surface, at least within the drilled area, is a discordant, gently undulating surface. One drill hole disclosed granophyre beneath the upper chilled zone of the lower diabase. Similar bodies of granophyre are known to occupy the higher parts of other thick diabase masses in York County and elsewhere in Pennsylvania. It is inferred that this diabase, which is beneath the ore deposits, may be 1,000 feet or more thick.

The upper diabase sheet is almost continuous at its south extremity with the main body of diabase; two narrow strips have been removed by erosion (fig. 3). The diabase sheet overlying the ore deposits undoubtedly was formerly continuous with the body to the south and constituted a minor offshoot. Drill-hole exploration has clearly shown that the lower diabase and the body that crops out to the south are also one and the same (see sec. A-A', fig. 3). Thus, at Dillsburg there is a plate of sedimentary rocks 100 to 500 feet thick between two flat-lying sheets of diabase. The bedding within the plate of sedimentary rocks is discordant with the surfaces of contact of the two diabase sheets.

The structural interpretation favored by the writer is that the diabase beneath the Dillsburg area is part of the same body that surrounds the district and is an offshoot of the Gettysburg sill to the east. It is a broadly concave, platter-like sheet that truncates the gently-dipping sedimentary rocks (sec. A-A', fig. 2).

In the Dillsburg area the sedimentary rocks have been disturbed by intrusion of the diabase. Uplift of the sedimentary rocks above the lower diabase sheet has caused an apparent horizontal displacement of the Heidlersburg member of the Gettysburg shale (fig. 2). A continuous belt of the Heidlersburg member is interrupted by the diabase, and a displaced segment is found in the nearly isolated plate of sedimentary rocks east of Dillsburg. The change of strike of the bedding east and southeast of Dillsburg may also be the result of tilting of the rocks above and adjacent to the intrusion.

The Cornwall District.—The magnetite deposits at Cornwall are situated on the north side of a small ring of diabase 7 miles south of Lebanon, Pa. (fig. 4). The deposits are in a wedge of limestone of Paleozoic age between Triassic sedimentary rocks on the south and diabase on the north. The diabase on the north has been interpreted by Spencer (1908, pp. 19-20) and others as a more or less vertical dike with a thin sill-like offshoot that comes to the surface at the south.

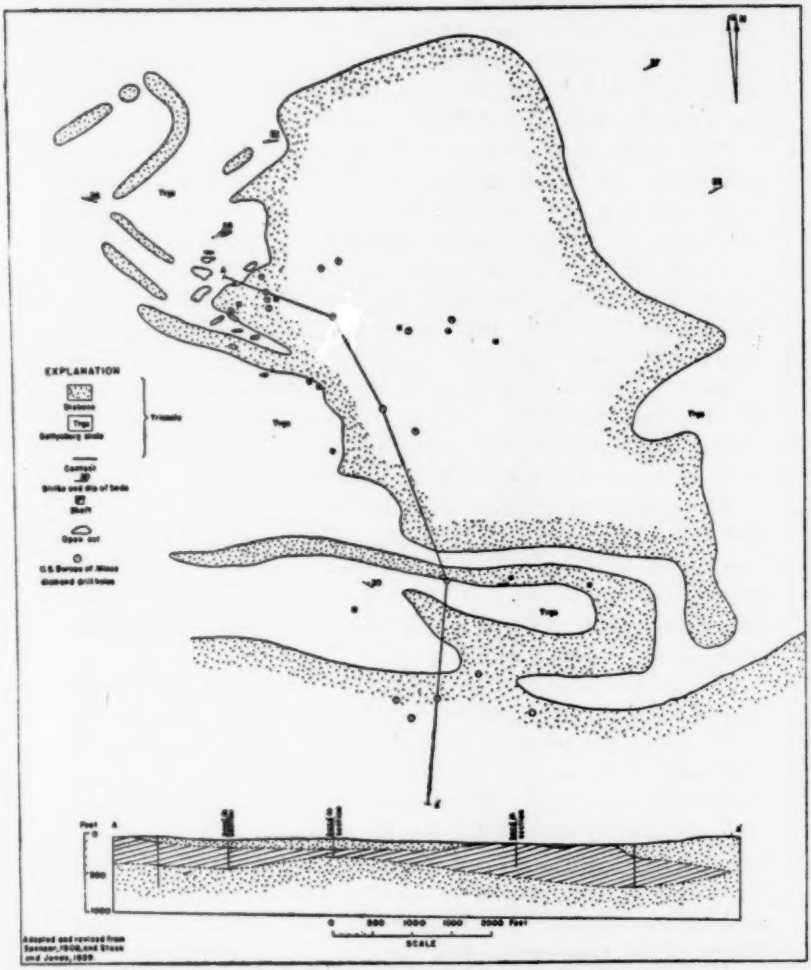

Fig. 3. Geologic map and section of the Dillsburg district, Pennsylvania.

As shown by diamond drilling, the diabase is a sheet about 1,000 feet thick that dips gently south (sec. A-A', fig. 4). Drilling toward the south and the center of the ring, which is occupied by Triassic sedimentary rocks, has shown that the diabase extends beneath the area, and becomes a nearly flat-lying body. The diabase is interpreted as a continuous shallow basinlike structure that is only locally concordant with the structure of the sedimentary rocks.

The Quakertown District.—At Quakertown, about 12 miles southwest of the Delaware River, there is an elliptical body of diabase whose long axis strikes northeast (fig. 5). A gravity survey was made in this area by Hersey (1944). Although at the surface Triassic sedimentary rocks occupy the center of the ellipse of diabase, a gravitational high over the area indicates the presence of diabase beneath a thin layer of sedimentary rocks. The gravitational pattern is symmetrical and conforms to the outcrop pattern of the diabase. The anomaly, according to Hersey, suggests a thickening of the diabase toward the central axis of the structure. Hersey states (1944, p. 439) that "the gravity anomaly could be caused by an intrusive roughly 100 feet thick near its edges and about

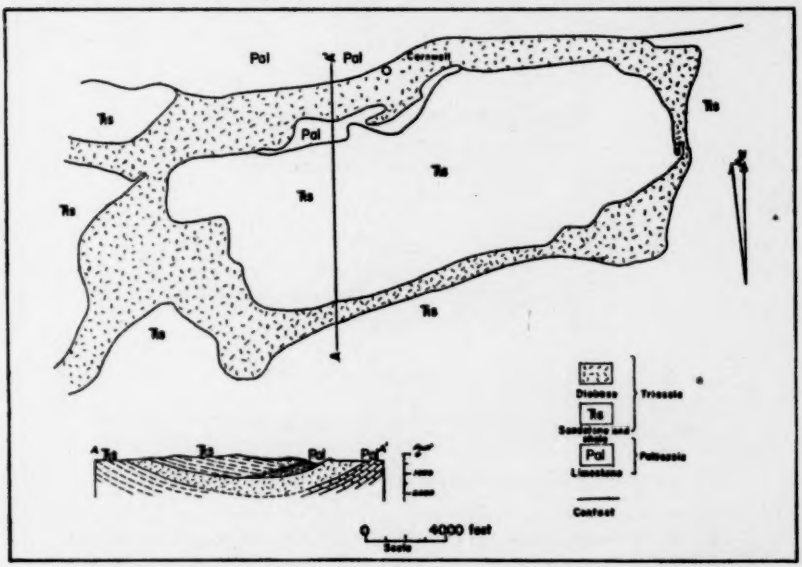

Fig. 4. Geologic map and section of the Cornwall district, Pennsylvania.

1,800 feet thick along its axis." Sections A-A' and B-B', figure 5, illustrate the possible structure of the diabase body as modified from a diagram by Hersey.

The Boyertown District.—The Boyertown magnetite deposits are at the western end of an elliptical ring of diabase,

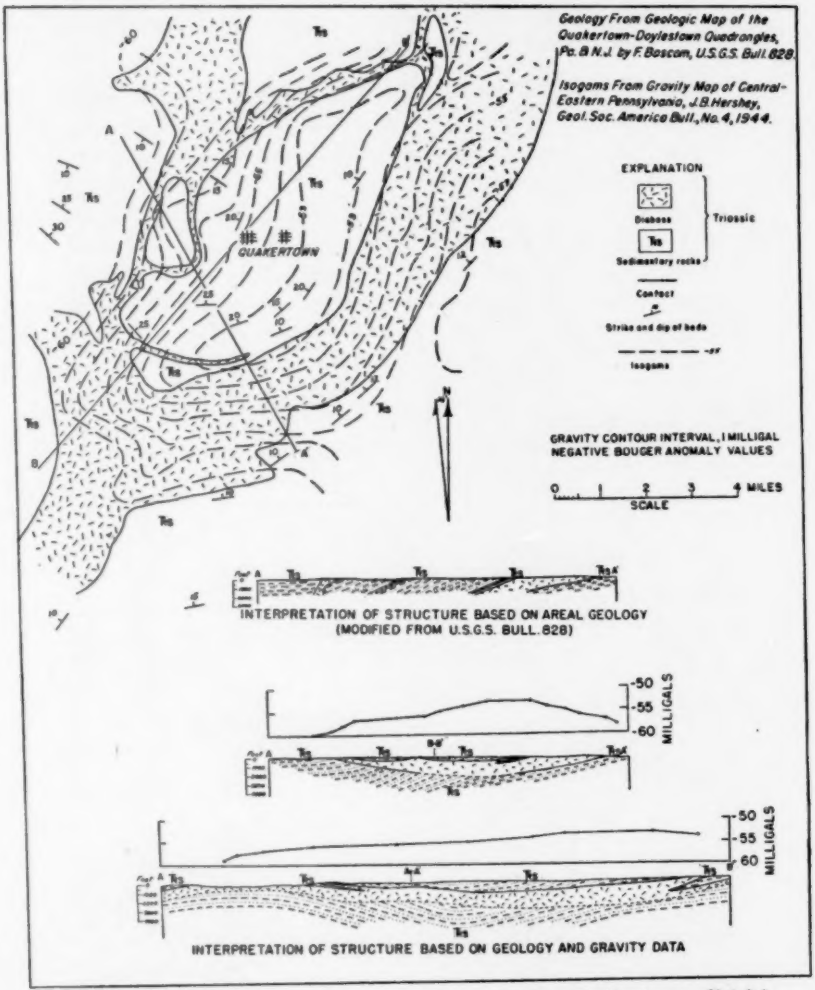
Geology From Geologic Map of the Quakertown-Doylestown Quadrangles, Pa. B N.J. by F. Boscom, U.S.G.S. Bull. 828.
Isogams From Gravity Map of Central-Eastern Pennsylvania, J.B. Hershey, Geol. Soc. America Bull., No. 4, 1944.
EXPLANATION
Diabase
Triassic
Sedimentary rocks
Contact
Strike and dip of beds
Isogams
QUAKERTOWN
GRAVITY CONTOUR INTERVAL, 1 MILLIGAL
NEGATIVE BOUGER ANOMALY VALUES
0 1 2 3 4 MILES
SCALE
INTERPRETATION OF STRUCTURE BASED ON AREAL GEOLOGY
(MODIFIED FROM U.S.G.S. BULL. 828)
-50
-55
-60
MILLIGALS
INTERPRETATION OF STRUCTURE BASED ON GEOLOGY AND GRAVITY DATA

Fig. 5. Geologic map and sections of the Quakertown district, Pennsylvania.

as shown in figure 6. The following discussion is based on an unpublished description by A. F. Buddington and H. E. Hawkes, who studied the deposits and mapped the western part of the elliptical structure.

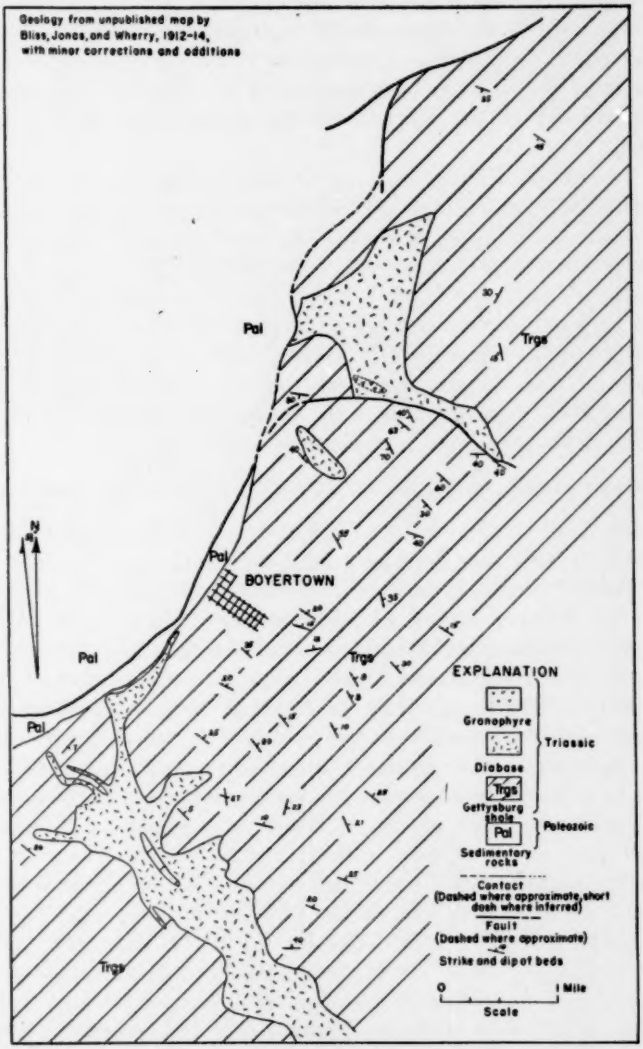

Fig. 6. Geologic map of the Boyertown district, Pennsylvania.

At least the western end, and possibly all, of the diabase ellipse occupies the flanks of a synclinal structure in the Triassic sedimentary rocks. The syncline in the vicinity of Boyertown is asymmetrical, for it dips more steeply on the north limb than on the south limb. The western end of the syncline apparently abuts discordantly against the contact between the Triassic sedimentary rocks and Paleozoic limestones. This contact, where it has been mapped in the couse of mining and exploration of the Boyertown ore bodies, dips 30° to 45° ESE.

The main diabase outcrop is interrupted in two places, leaving a large isolated area of diabase about 2 miles north of Boyertown. It may be reasonably inferred that this diabase body connects at depth with the diabase that crops out to the south and east (figs. 1 and 6) and is an integral part of the major igneous structure. Local exposures of granophyre similar to the exposure at Dillsburg were found near the southwest edge of the isolated body (fig. 6). The position of the granophyre suggests that it is in the upper part of a thick sheet of diabase dipping moderately to the south.

COMPARISON WITH DOLERITE SHEETS OF SOUTH AFRICA

Du Toit (1920), Scholtz (1936), and Walker and Poldervaart (1949) have described dolerite intrusions in the Karroo system of South Africa that are remarkably similar in form to the diabase bodies of southeastern Pennsylvania. Most of the sill-like intrusions are curved sheets whose ". . . outcrops . . . determined chains of hills snaking across the country" (Du Toit, 1920, p. 7). Figure 7, taken from Du Toit's paper, shows the irregular ringlike plan of the outcrop of these intrusions. Almost the exact counterpart is found in figure 1, which shows in plan the diabase bodies of southeastern Pennsylvania. The sheets of East Griqualand and Pondoland studied by Scholtz (1936) are well known because of their associated nickeliferous ore deposits. According to Scholtz many of the sheets are rudely circular in plan and have a basinlike structure with diameters up to 10 miles and thicknesses ranging from 1,000 feet or less to 3,000 feet or more. The sheets have rudely parallel, but markedly undulatory, upper and lower surfaces. Walker and Poldervaart (1949, pp. 605, 608) describe and illustrate undulating dolerite sheets that have pronounced anticlinal rolls as well as syn-

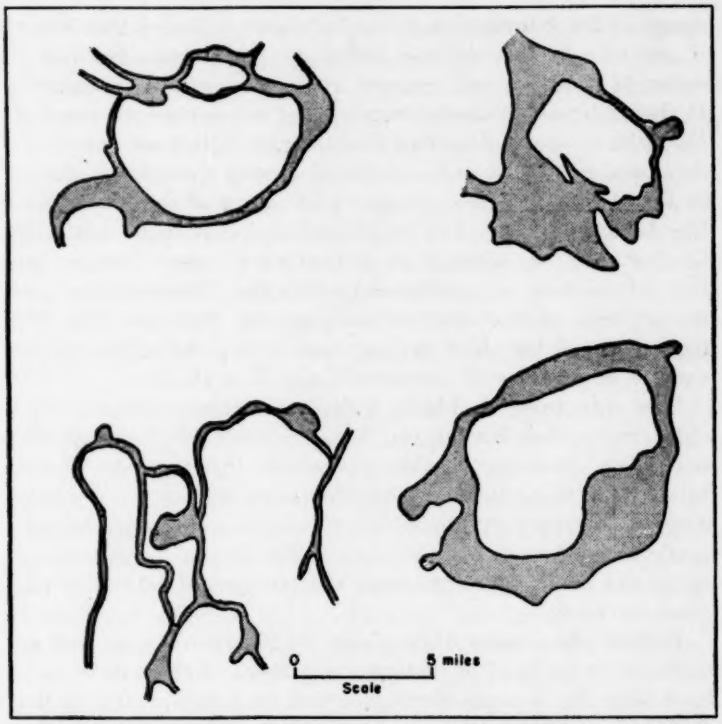

Fig. 7. Types of curved intrusive sheets of Karroo dolerite (stippled) in plan.

clinal or basinlike forms. No real anticlinal structures have been recognized in the diabase sheets in Pennsylvania.

The South African dolerite sheets are discordant intrusions; but, unlike the bodies in Pennsylvania that intruded generally westward-dipping, locally gently folded beds, the sheets in South Africa intruded essentially horizontal rocks.

ORIGIN OF THE DIABASE SHEETS

In this part of Pennsylvania there are few true sills in the usual meaning of the term. The sill east and northeast of Gettysburg apparently fulfills the requirements of the definition, for in most places it is a gently inclined concordant body. The many other bodies of diabase with their elliptical or circular outcrop patterns are in part concordant with the bedding of the enclosing sedimentary rocks but in many places they are discordant. Although the data are not yet

complete the information presented above indicates that many if not all of these diabase bodies are continuous beneath a cover of Triassic sedimentary rocks and are basin-shaped. It should be emphasized, however, that in contrast to some of the dolerite sheets described from South Africa no true well-developed anticlinal rolls are found among the diabase sheets in Pennsylvania. The succession of a series of shallow, basin-like bodies suggests that in places, as for example south of Quakertown, the diabase is a continuous sheet because of the intersection of platter-shaped bodies. Erosion has removed some of the cover of sedimentary rocks so that the high parts of the sheet are exposed, giving the effect at the surface of a series of connected links in a chain.

The only form in which diabase intrusions occur in the older rocks that border the Triassic basin of Pennsylvania is as dikes. Perhaps the older rocks with their complex structures were more resistant to the intrusion of the diabase magma, and they restricted its course to a few well-defined, predetermined vertical fractures. In the Triassic sedimentary rocks the invading magma was able to spread laterally and raise its roof.

Diabase dikes occur throughout the Triassic belt as well as in the older rocks of adjoining areas. Some of these dikes may have been the avenues through which magma was fed to the sheets. Some of the sheets may be in part offshoots from larger intrusions. For example, the large body of diabase east of Dillsburg and the sheet beneath the magnetite deposits appear to be offshoots from the Gettysburg sill. Some of the diabase may have risen along fault zones at the northwest border of the Triassic basin.

The mechanism that controlled the basinlike form assumed by these intrusions is not clearly understood. The curved form of the diabase sheets might be interpreted as being due in part to the development of nearly horizontal to gently undulating fractures in the Triassic sediments. These fractures were subsequently filled with magma that crystallized as diabase. Where these fractures were joined, the filling of diabase was continuous. Du Toit (1920, p. 29) suggested that the curving form in the Karroo dolerites ". . . may have been partly or wholly determined under the stresses set up through thermal expansion." Steep fractures, formed during the tilt-

ing of the Pennsylvania Triassic basin, probably served as conduits through which the diabase magma rose into the accumulated sedimentary rocks. Perhaps relatively horizontal or basin-shaped fractures were also formed at this time.

Scholtz (1936, p. 202), discussing the mechanism of intrusion of the Karroo dolerites, postulates that the initial stages of magmatic activity resulted in ". . . the extrusion of great quantities of lava at the surface, which eventually consolidated and acted as an effective barrier to the escape of the rising magma, which now penetrated potential lines of weakness developed in the still subsiding sediments." So far as is known there was no thick overburden of lava in the Pennsylvania Triassic basin.

Scholtz pictures ". . . the injection [of magma as sheets] . . . as being of the nature of a mutual exchange of place between the settling sedimentary formations and a concomitant hydrostatically elevated quantum of magma . . ." without causing any arching of the roof. Du Toit (1920, p. 28), on the other hand, considers that introduction of the Karroo sills must have ". . . produced vertical uplift of the overlying strata amounting to the thickness of the intrusion at that point measured vertically." As we have seen in the intrusion at Dillsburg, there is evidence of uplift and disturbance of the overlying sedimentary formation (p. 379).

Probably no actual fractures were necessary for the magma to assume a sheetlike form. It may have been easier for the magma to spread laterally than to rise to higher levels. Under these circumstances the magma could probably make its own way by starting with initial irregularities in the conduit walls or by following potential planes of weakness brought about by tension in the block of subsiding sediments. According to Anderson (1942, pp. 23, 142) the thin edge of an advancing magma sheet has a powerful wedging effect by means of which it is able to advance itself. Du Toit (1920, p. 5) has also suggested that lateral spread may be aided by water vapor released from the sediments as they are heated by the magma.

ACKNOWLEDGMENTS

The field work on which this report is based was part of the study of the Triassic magnetite deposits of the Dillsburg district by the U. S. Geological Survey under the direction

of A. F. Buddington. I am indebted to Princeton University for office facilities and to Professor Buddington for his interest and helpful suggestions during the investigation.

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U. S. Geological Survey
Salt Lake City, Utah

REVIEWS

Silicate Melt Equilibria; by WILHELM EITEL. Pp. x, 159; 200 figs. New Brunswick, New Jersey, 1951 (Rutgers University Press, $5.00).—This book will be of great value to those who are interested in phase equilibrium of silicates, and especially to petrologists and ceramists. The theoretical discussion is along classical lines. It is clear and not too wordy, and the numerous illustrations chosen from actual silicate systems will be helpful. Probably the numerous figures to some extent account for the high price.

The reviewer wishes that those who write on the Phase Rule would bring out the fact that the common statement, $P + F = C + 2$, is a qualitative generalization incidental to a quantitative thermodynamic treatment. The treatises of Bakhuis-Roozeboom and his successors are based on much more than this qualitative ment by Van der Waals, probably Gibbs' greatest disciple, with generalization. They are based chiefly on the thermodynamic treatspecial emphasis on the zeta function. Failure to mention this fact leads to a misconception of the nature of the whole treatment of Phase Equilibrium, which is an expression of the application of the first and second laws of thermodynamics to chemical systems.

The reviewer agrees with the author (p. 78) in preferring the term "boundary curve" to "eutectic curve"; the term "eutectic" should be applied only to invariant points, never to univariant equilibria. The use of "transition point" to designate incongruent melting is frequent and unfortunate. "Transition" should be restricted to change from one allotropic form to another, "polymorphous inversions." Bowen's term, "reaction point," is excellent. Also, the reviewer does not share Eitel's objection to the term "solid solution," which is preferable to the suggested "crystalline solution."

Despite these differences of opinion, the reviewer stands by his opening statement concerning the usefulness of this book to those interested in silicate chemistry, and it can be recommended without reservation.

GEORGE W. MOREY

An Advanced Treatise on Physical Chemistry. Volume II. The Properties of Liquids; by J. R. PARTINGTON. Pp. xliv, 448. London, 1951 (Longmans, Green and Co. Ltd., $10.00).—This continuation of a treatise, the first volume of which has previously been reviewed in this JOURNAL (Vol. 248, pp. 444-446, 1950), summarizes our present knowledge of the general physical chemistry of the liquid state. After a brief introductory discussion of the molecular theory of liquids, the equation of state, the viscosity, the thermal

conductivity, the surface tension, the specific heat, the vapor pressure, the boiling point, and the latent heat of evaporation of liquids are reviewed. The volume is concluded by two additions to the mathematical discussion, covering determinants, matrices and groups, and coordinate geometry of three dimensions. It should be noted that although the full treatment of the properties of solutions is deferred to a later volume, data on the equation of state, viscosity, and surface tension of solutions appear along with similar data for pure liquids. Noteworthy omissions from the list of properties considered are the electrical, magnetic, and optical properties of liquids. It is to be hoped that these will be discussed at some appropriate place in a later volume, since they are of interest to many modern physical chemists.

The features which distinguished the first volume have been retained: the number of references is again large, including both pioneering research and later developments through June, 1950. The total number in this volume is 11,758! The emphasis on experimental techniques and on empirical representation of results is even more apparent than before, while the occasional pithy comments on various controversial subjects give welcome relief from a monotonous rehearsal of facts, techniques, and theories.

The limitations of single authorship in a work of this magnitude are also detectable. Although Professor Partington has digested the published literature in the various fields in a remarkable fashion, the specialist is likely to find his conclusions occasionally at variance with current opinion on controversial topics, especially when this has crystallized without being formally reported. Examples of this sort are his mention of the *resonance* of the hydrogen atom in hydrogen bonding, and his discussion of the Jones-Ray effect in surface tension measurements. His definition of a matrix and its relation to a determinant is also rather confused.

For a work of this magnitude, surprisingly few misprints were noted, and most of those which occurred were trivial. Errors of this type detected in Volume I are corrected in a page and one-half errata section in this volume. The smallness of this section testifies to the care of the author and publisher in attending to details.

The general conclusions in the review of the first volume as to the value of this series apply to Volume II as well. The third volume, promised for early 1952, is to deal with the solid state, and should be of particular interest to geologists, as well as to chemists and physicists.

HENRY C. THACHER JR.

Ultrasonics; by P. Vigoureux. Pp. vi, 163; 74 figs. New York, 1951 (John Wiley & Sons, Inc., $4.00).—In the past few years

there has been an ever-widening interest in sound—especially in the frequency region above the audible range. Despite this interest, few books on ultrasonics have appeared. Bergmann's standard work in the field was published in 1938. It is therefore a pleasure to receive this up-to-date simple treatise by Vigoureux, which helps to bridge the gap between Bergmann and the present. The author treats briefly the theory of sound generation and propagation and reviews typical experimental techniques, followed by brief summaries of the results of ultrasonic investigations in gases and liquids. He makes no attempt to be exhaustive in coverage except for his bibliography wherein he reviews the field since the publication of Bergmann's treatise. To the newcomer to ultrasonics this book provides a simply written introduction and an excellent guide to the literature.

HENRY A. FAIRBANK

Semi-conductors; by D. A. WRIGHT. Pp. viii, 130; 32 figs. New York and London, 1950 (John Wiley & Sons, Inc., and Methuen & Co., Ltd., $1.75).—This small pocket-size book is another valuable addition to Methuen's Monographs on Physical Subjects. The author's stated intention is to give an elementary account of the properties of semi-conductors with emphasis on the theory of electron flow in them, and across the boundary between them and either a metal or a vacuum. He succeeds in bringing to the non-specialist a simple and brief account of this active research field to which he has liberally contributed. Some readers may share my feeling that topics are too briefly presented—e.g. the properties of transistors—but this is not a fair criticism since the small size of the book precludes too detailed a treatment of any one topic. By taking time from his research to write this little book, the author has performed a real service to those who wish to acquaint themselves with the current work in semi-conductors but, for one reason or another, cannot take the time to read and digest the scattered literature in the field.

HENRY A. FAIRBANK

How to Study, How to Solve, Arithmetic through Calculus; by H. M. DADOURIAN. Pp. vi, 121; paper covers, 12-mo. Cambridge, Mass., 1951 (Addison-Wesley Press, Inc., $.60).—This pocket-sized book contains many hints and suggestions on the solving of problems. Its use will probably improve the ability of the good student by showing him how to systematize his study habits, and it may help a poor student to eliminate some of his difficulties. The suggestion in the title, that its use is limited to students of

mathematics, is quite unnecessary; and might perhaps be removed by rephrasing the subtitle approximately as follows: "with mathematical examples from arithmetic through calculus." At least a quick perusal of the booklet is recommended for all students.

Wavelength Tables of Sensitive Lines; by L. H. AHRENS. Pp. viii, 86. Cambridge, Mass., 1951 (Addison-Wesley Press, Inc., $3.00).—Professor Ahrens has produced here a short but useful handbook for geologists, mineralogists, and others interested in the spectrographic and spectroscopic identification of the elements present in rocks and minerals. The three or four most sensitive lines of each element included in the tables (69 in all) are shown, together with nearby lines of other elements. The range of wavelengths included is limited to that determined by "ordinary" spectrographic techniques, namely 2200 to 9000 angstroms. The sensitivities and probable interferences of various lines are indicated for each element. A short table of visual (spectroscopic) lines is included.

HORACE WINCHELL

Geology and Barite Deposits of the Del Rio District, Cocke County, Tennessee; by H. W. FERGUSON and W. B. JEWELL. Pp. 235; 6 figs., 43 plates. Tennessee Department of Conservation, Division of Geology Bulletin 57. Nashville, 1951.—Although this report gives principal emphasis to economic mineral deposits, it presents also material of much interest and value to stratigraphers and structural geologists. The area described is in the belt of great thrust faults near the Tennessee-North Carolina boundary, a belt in which considerable work is currently being done (Tennessee Div. Geology Bull. 52, 1944; North Carolina Dept. Cons. and Devel. Bull. 60, 1950; work in progress by U. S. Geological Survey in the Great Smoky Mountains National Park). Sedimentary formations that make up the bedrock consist chiefly of clastic materials, and are classified as partly Lower Cambrian, partly of unknown (possibly Precambrian) age. This sedimentary section, with total thickness about 10,000 feet, is cut by a number of important thrust faults, and is affected by several large folds that plunge steeply northeastward. Two of the thrusts are low-dipping, and each of these is responsible for displacement measured in miles. Other thrusts have steep dips in outcrop, and presumably coalesce at depth with a flat sole fault. Each thrust is intersected by the one next higher structurally.

Folding of the thrust sheets was less intense than in some other parts of the southern Appalachians; only one of the large thrusts

dips northwestward at the outcrop. The only evidence of metamorphism consists of slaty cleavage in some of the shales, and this is localized in or near zones of major thrusting.

Masses of barite, with a number of accessory minerals, occur along thrusts and related zones of shearing. In a common type of deposit fine-grained barite has replaced quartz and feldspar in mylonite and related bands of crushed rock. Elsewhere coarse-grained barite and accompanying minerals are in definite veins. Since 1880 about 55,000 tons of barite have been produced in the district, and authors of this report estimate that reserves at two of the active mines amount to many times the tonnage already removed. About four-fifths of the text of the report is devoted to economic geology, largely to descriptions of barite mines and prospects.

A colored geologic map, on the T.V.A. base with scale 1:24,000 and contour interval 20 or 40 feet, represents an area of irregular form, with maximum dimensions about 19 by 8 miles. Five structure sections accompany the map. The text of the report is lithoprinted and is very clear. Halftone reproductions of photographs, featuring landscapes, outcrops, hand specimens, and thin sections, are only moderately successful.

CHESTER R. LONGWELL

Handbuch der Gletscherkunde und Glazialgeologie, Vols. 1 and 2; by R. von Klebelsberg, Pp. 1028; 92 figs. Vienna, 1948 and 1949 (Springer-Verlag, vol. 1, $15.80 unbound; vol. 2, $22.80 unbound). —Despite its forbidding price, this book will be widely sought after, for it is a reference work of major proportions and major value. Appropriately dedicated to Albert Heim and Albrecht Penck jointly, it is the fruit of the author's labors during the war years 1939-1945.

As editor of the *Zeitschrift für Gletscherkunde* since 1928 in succession to Brückner, von Klebelsberg has been in close and continuous touch with new developments in the study of glaciers and glacial geology. His journal has published contributions from all over the world. During the war years, when the *Zeitschrift* was obliged to suspend publication, he made excellent use of the wealth of information that lay accumulated, ready to his hand. Hence these volumes are a vast storehouse of data, not simply arranged in logical sequence, but carefully sifted through a mind well equipped with a knowledge of glaciers, acquired throughout a professional lifetime.

This publication can only be described as massive. The number of references to the literature alone approaches the astronomic; yet these are so thoughtfully arranged that they are not oppressive;

they do not overshadow the text. Of course references dating from the years since 1939 are incomplete, especially from areas outside Europe, and parts of the text must be read with this fact in mind, for important advances have been made, especially in America, since before the war.

The subject index alone runs to 100 two-column pages.

The book follows a systematic pattern with great thoroughness. The pattern is entirely conventional, and rightly so for a work that will enjoy the widest use as a reference. The first quarter deals with glaciology, the second quarter with physical glacial geology, and the third and fourth quarters with historical, regional, and stratigraphic aspects of the Pleistocene and pre-Pleistocene glaciations.

On many controversial matters the author presents, not merely a digest of the divergent views, but a critical summary reflecting his own judgment. For example, on the vexed question of glacier motion he is eminently fair, concluding that no satisfactory explanation has been reached as yet.

The work reflects many of the new ideas that have been incorporated into the body of glacial knowledge since the appearance of such classic general volumes as those of Heim and Hess. The more recent hypotheses of glacier motion, the studies, first begun by Ahlmann, on the regimens of existing glaciers, the mechanics of glacial erosion, the role of dead ice in glacial deposits—to name a few—are well represented. Also there are particularly detailed and thorough histories of the study of glaciers and of the development of the concept of former widespread glaciation.

There is nothing informal about this book. It is solid meat. It never deviates from its objective of presenting as much information as possible as concisely as possible.

Quite naturally the author's long experience of the Alpine region enables him to view with greater insight the glaciers, the valleys, and the drift of high-mountain regions, and the Alps in particular, than those of lowlands; he is expectably more at home in the physical geology of glaciers than in the stratigraphy of the Pleistocene. This is not a criticism; it merely expresses an entirely proper limitation of the book's scope. A treatment of Pleistocene stratigraphy in the same detail as that given to physical glacial geology would probably run, with references, to another thousand pages! The emphasis on mountain areas rather than on lowland areas is the more welcome inasmuch as British and American works have tended to an opposite emphasis.

The reader should not look here for the climatic viewpoint as a dominant feature; this is a book about glaciers, and in it climate

takes a subordinate place. Nor should he look for more than a brief treatment of the great secondary effects of glaciation, such as eustatic fluctuation of sealevel and isostatic movements of the Earth's crust. The author does not pretend that they are a direct part of his subject which, once more, is glaciers.

For the truly herculean labor which von Klebelsberg has put into this massive synthesis, all workers in glaciology and glacial geology owe him a debt of gratitude.

RICHARD FOSTER FLINT

Diccionario Minero - Metalurgico - Geologico - Mineralogico - Petrografico y de Petroleo; by ALEJANDRO NOVITZKY. Pp. 369. Buenos Aires, 1951 (Obtainable through "El Ateneo," Florida 340-344, Buenos Aires, 120 pesos).—This authoritative and comprehensive book contains compilations of mining, metallurgical and geological terms in five languages, viz. English, Spanish, French, German and Russian.

The author was associated with geological institutions in France, Germany, Yugoslavia and Bulgaria. He was also engaged in such diverse activities as mining engineering in coal and copper, oil geology, metallurgical work and lecturing on mineralogy and mining subjects. He was therefore well qualified for the ambitious project of preparing this dictionary. A native of Russia, he is at present lecturer in Argentina.

Great stress has been placed on mining terminology. The author notes that a serious obstacle was the absence of many mining terms in Spanish that are of common use in other languages. Many new terms therefore had to be introduced. Machinery and mining equipment are treated in great detail. For example, thirty different terms are quoted under blast furnace, such as blast furnace charging device, blast furnace hoist, blast furnace slag. The list of minerals is exhaustive for a dictionary of this type. Many rare minerals are included, such as hoegbomite and bassetite. The list of minerals on page 238 includes the following in alphabetical order: phoenicochroite, pholerite, pholidolite, phosgenite. The rock names likewise have been given careful consideration; lherzolite, markfieldite, jacupirangite, evergreenite are examples of those mentioned. Stratigraphic expressions as well as terms from physics, chemistry and geography that are commonly used in geology have been included.

Gaps are occasionally encountered. In many cases the Russian translation has been omitted. The reason may have been that the

author did not know the equivalent Russian term, or that no references to the corresponding expression can be found in the Russian literature. The mineral hoegbomite has been reported in English, French and German mineralogical publications, but not in Russian. Consequently the Russian translation has been omitted. The Spanish translation hoegbomita must have been made up by the author. Omissions in Spanish, French and German are less common.

The great drawback of the book for someone whose native tongue is English is that the English version is arranged in alphabetical order instead of the foreign terms. Someone engaged in literature search is not likely to be interested in what "piling and welding of steel" is in Spanish, German or Russian, but when hitting upon an unfamiliar term in the foreign language will want to know its English equivalent. However, in order to produce a book in which this handicap is overcome its thickness has to be increased fourfold. Still, there ought to be demand for an excellent up-to-date set of volumes of Spanish-English, French-English, German-English and Russian-English for the geologist.

GERALD M. FRIEDMAN

Igneous and Metamorphic Petrology; by FRANCIS J. TURNER and JEAN VERHOOGEN. Pp. 602; 92 figs. New York, Toronto, London, 1951. (McGraw-Hill Book Company, Inc., $9.00).—The authors state that this book is intended for advanced students, research workers, and teachers in the field of petrology.

There has been no textbook published in English for advanced students of the petrology of igneous rocks since those by Harker (1909), Iddings (1909) and Daly (1914), though of course we had the remarkable group of essays on special topics by Bowen (1928) and several texts suitable at a more elementary level. Textbooks on metamorphism were published in English by Leith and Mead (1915) and by Harker (1932). None of the foregoing books however are at all adequate at the present time. There has long been a desperate need for a book on the igneous and metamorphic rocks treated from the standpoint of petrogenesis for advanced students. The book under review superbly meets this need. It is a "must" for every "hard rock" petrologist and economic geologist, and will serve as an excellent authoritative reference book for all students of geology and for scientists in allied fields. The two authors, both now in the Department of Geological Sciences at the University of California, have brought to their task a varied background of education and experience. The fol-

lowing data are taken from American Men of Science: Jean Verhoogen, Min. Eng., Brussels, '33; Geol. Eng., Liège, '34; Ph.D. (volcanology), Stanford, '36. Asst. geol. Brussels, '36-39; geological engineer Belgian Congo '40-'46; assoc. prof. geol. California '47-. F. J. Turner, M.Sc. '26 and D.Sc. '34, New Zealand; Lecturer and Senior Lecturer Otago, N.Z. '26-'46, assoc. prof. and prof. California '46-. The choice of examples in some instances to illustrate principles is obviously related to the personal experience and background of the authors and brings for Americans a certain freshness to the book not otherwise probable. It is completely up to date on the literature and papers as late as 1950 are referred to.

The book contains 14 chapters (343 pp.) in the part on igneous rocks and 8 chapters in the part on metamorphism (238 pp.). Four of the chapters on igneous rocks and one on metamorphism are largely on pertinent principles of physical chemistry. The part on metamorphism is effectively the material of Geological Society of America Memoir 30 (Evolution of the metamorphic rocks), somewhat reduced and revised. The chapter (16) on chemical principles in metamorphism in particular has been very much enlarged (39 pages) with new material.

The classification of igneous rocks receives but brief treatment, a little over five pages. The part on classification really could stand a wee bit of expansion. For example, something should be added to explain why limburgite is described as having an ultrabasic glassy base when it has so much of salic matter in its composition, and some mention might be made of the occurrence of free SiO_2 (as necessitated by norms) in many andesites. A differentiation of the gabbro family into gabbro, hypersthenic gabbro, and norite on the basis of the ratio of hypersthene to augite seems necessary for present day petrology rather than calling gabbro a norite as soon as it has a hypersthene grain in it. The term oceanite is referred to several times in the text but the definition is hazy. The enigma of the lamprophyres is either inadvertently or deliberately emphasized by their classification as a family of the "volcanic rocks" though their major discussion is under "plutonic" rocks. A couple of slips have crept in; the phrase "may be" probably was left out where part of the definition of pegmatites states they are mineralogically complex, and where aplite is defined as a "white" rock, "dike" rock may have been meant.

Throughout the book the major treatment of the igneous rocks

is not as separate distinct species but as kindreds and petrographic provinces. This procedure works very well, but some problems such as that of diorites receive scanty treatment. The classification of rock series by Peacock is used so much in the book that the method of construction on which it is based might well have been given in greater detail. Some book, some day must carry a thorough discussion and review of the igneous rocks of such orogens as the Sierra Nevada and Alaska-British Columbia coast ranges and the Appalachians. In the latter case the requisite data aren't available at present for the northeastern part in the Canadian provinces including Newfoundland, where there is perhaps the fullest story.

The part on igneous rocks is written largely from the standpoint of "magmatists" (the reviewer would also add, well-balanced magmatists with a knowledge and understanding of the limitations of both the field and laboratory evidence). In the light of orthodoxy in many quarters today this will be considered a major defect in the book. However, the hypothesis of large scale "granitization" has now been given intensive consideration for over a quarter of a century. Historically, in our science, this has proven to be the normal length of time for the exploitation of a new idea, after which the spiral of thought swings back to a modified form of an old hypothesis. The old hypothesis in this case may well prove to be the "magmatic" concept and the book under review may well be *ahead of* rather than, as I am sure some "transformationists" would say, *behind* the times. The authors are clearly aware of both the limitations and need of experimental data, for they write "It is indeed a bold extrapolation from crucible to magma. The study of processes occurring in crucibles remains nevertheless an essential step in the understanding of processes that are operative in magmas."

The authors state in the preface that the book is based on data too voluminous to be grasped and handled by one or even two individuals. The reviewer has the most intense sympathy for this statement, for he has found the matter in the book itself too diverse, complex and voluminous to handle adequately in a review. Every geologist should find something of interest in this book.

A. F. BUDDINGTON

A NEW JOURNAL FOR STUDENTS OF THE PLEISTOCENE

American scientists concerned with Pleistocene problems will be interested in the appearance of a new German periodical,

EISZEITALTER UND GEGENWART. The journal, to be published annually by the Deutsche Quartärvereinigung, is edited by the dean of German Pleistocene geologists, Dr. Paul Woldstedt. Volume 1, which appeared toward the end of 1951, contains 17 papers of excellent quality. These reflect the broadening of Pleistocene research that has been taking place steadily during the past two decades, through the integration of various scientific disciplines. Geology, Biology, Climatology, Anthropology, and Geography are represented in this single issue, and in the assemblage a striving for syntheses reaching beyond the bounds of any one science is evident. That this effort is deliberate and concerted is made clear in an excellent foreword by the Editor.

Libraries and individuals in the United States and Canada can subscribe to EISZEITALTER UND GEGENWART at $3.00 a year through its Editor, whose address is: Am Kleinen Felde 12, Hannover, Germany.

R. F. FLINT

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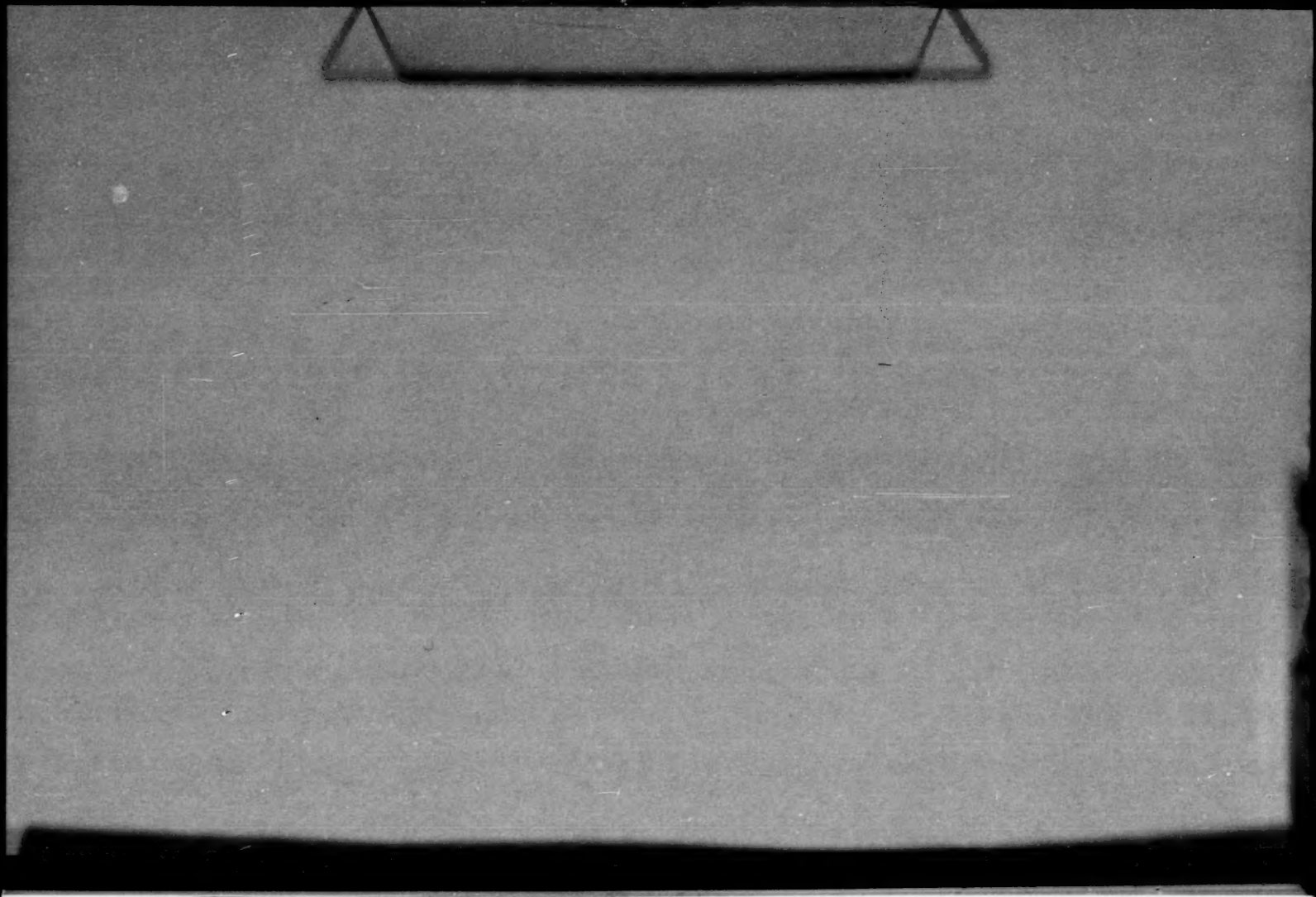

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